



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
28.08.2019 Bulletin 2019/35

(51) Int Cl.:
F21K 9/64 ^(2016.01) **H01L 33/50** ^(2010.01)
F21Y 115/10 ^(2016.01) **H01L 25/075** ^(2006.01)
H01L 33/58 ^(2010.01)

(21) Application number: **19166740.1**

(22) Date of filing: **29.05.2007**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC MT NL PL PT RO SE SI SK TR

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(30) Priority: **20.12.2006 US 642089**

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
07809225.1 / 2 102 918

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Remarks:
This application was filed on 02-04-2019 as a divisional application to the application mentioned under INID code 62.

(54) **LIGHT EMITTING APPARATUS USING MULTIPLE COLORED RADIATION EMITTING SOURCES AND A DOWN CONVERSION, DIFFUSER ELEMENT**

(57) A light emitting apparatus (710) includes: a substrate (703); a plurality of multiple colored radiation emitting sources (701) on the substrate; a down conversion material layer (706) on the plurality of multiple colored radiation emitting sources for receiving at least a portion of the multiple colored radiation emitted by the plurality of sources (701) and converting the radiation into forward transferred light radiation, or transmitted light radiation, and back transferred light radiation, or reflected light radiation; and an optic device (704) disposed on the plurality of multiple colored radiation emitting sources and coupled to the down conversion material layer. The down conversion material layer (706) of said light emitting apparatus (710) includes a plurality of down conversion materials (706A, 706B, 706C, 706D) distributed in segments having densities different from each other.

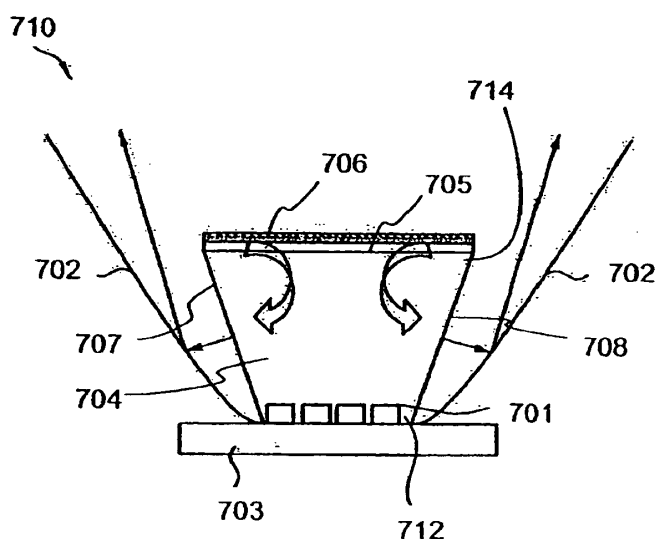


FIG. 7A

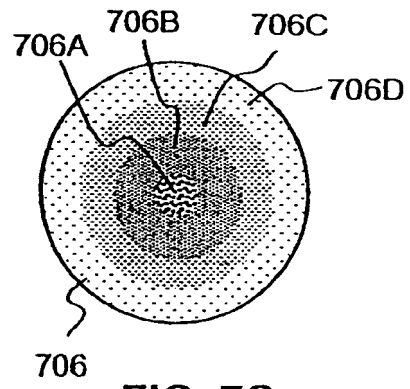


FIG. 7C

Description

[0001] This application claims the priority of US. 11/642,089, filed December 20, 2006.

BACKGROUND OF THE INVENTION

[0002] Solid state light emitting devices, including solid state lamps having light emitting diodes (LEDs) and resonant cavity LEDs (RCLEDs) are extremely useful, because they potentially offer lower fabrication costs and long term durability benefits over conventional incandescent and fluorescent lamps. Due to their long operation (burn) time and low power consumption, solid state light emitting devices frequently provide a functional cost benefit, even when their initial cost is greater than that of conventional lamps. Because large scale semiconductor manufacturing techniques may be used, many solid state lamps may be produced at extremely low cost.

[0003] In addition to applications such as indicator lights on home and consumer appliances, audio visual equipment, telecommunication devices and automotive instrument markings, LEDs have found considerable application in indoor and outdoor informational displays. With the development of efficient LEDs that emit short wavelength (e.g., blue or ultraviolet (UV)) radiation, it has become feasible to produce LEDs that generate white light through down conversion (i.e., phosphor conversion) of a portion of the primary emission of the LED to longer wavelengths. Conversion of primary emissions of the LED to longer wavelengths is commonly referred to as down-conversion of the primary emission. An unconverted portion of the primary emission combines with the light of longer wavelength to produce white light.

[0004] Phosphor conversion of a portion of the primary emission of the LED chip is attained by placing a phosphor layer in an epoxy that is used to fill the reflector cup, which houses the LED chip within the LED lamp. The phosphor is in the form of a powder that is mixed into the epoxy prior to curing the epoxy. The uncured epoxy slurry containing the phosphor powder is then deposited onto the LED chip and is subsequently cured.

[0005] The phosphor particles within the cured epoxy generally are randomly oriented and interspersed throughout the epoxy. A portion of the primary radiation emitted by the LED chip passes through the epoxy without impinging on the phosphor particles, and another portion of the primary radiation emitted by the LED chip impinges on the phosphor particles, causing the phosphor particles to emit longer wavelength radiation. The combination of the primary short wavelength radiation and the phosphor-emitted radiation produces white light.

[0006] Current state of the art phosphor-converted white LED (pc-LED) technology is inefficient in the visible spectrum. The light output for a single pc-white LED is below that of typical household incandescent lamps, which are approximately 10 percent efficient in the visible spectrum. An LED device having a light output that is

comparable to a typical incandescent lamp's power density necessitates a larger LED chip or a design having multiple LED chips. Moreover, a form of direct energy absorbing cooling must be incorporated to handle the temperature rise in the LED device itself. More particularly, the LED device becomes less efficient when heated to a temperature greater than 100°C., resulting in a declining return in the visible spectrum. The intrinsic phosphor conversion efficiency, for some phosphors, drops dramatically as the temperature increases above approximately 90°C threshold.

[0007] U.S. Patent No. 6,452,217 issued to Wojnarowski et al. is directed to a high power LED lamp or multiple LED lamp design for use in lighting products and a source of heat removal therefrom. It has LED die arranged in a multi-dimensional array. Each LED die has a semiconductor layer and phosphor material for creation of white light. A reflector gathers and focuses the light from each of the die to approximate a high power LED lamp. Fig.12 of the Patent illustrates a multi-sided array which emits light at angled ray trace paths. Fig.19 of the Patent illustrates the LED lamp head being angled.

[0008] U.S. Patent No. 6,600,175 issued to Baretz et al. and U.S. Patent Application Publication No. 2004/0016938 filed by Baretz et al. are directed to solid state light emitting devices that produce white light. The '938 patent application publication is a continuation of the '175 patent. The solid state light emitting device generates a shorter wavelength radiation that is transmitted to a luminophoric medium for down conversion to yield white light. In Figs. 2 and 6 of the Patent, there is a spaced relationship between the LED and the luminophoric medium. In Fig.6, for example, light is emitted from the solid state device 82 of shorter wavelength radiation, preferably in the wavelength range of blue to ultraviolet. When luminophoric medium 90 is impinged with the shorter wavelength radiation, it is excited to responsively emit radiation having a wavelength in the visible light spectrum in a range of wavelengths to produce light perceived as white.

[0009] U.S. Patent No. 6,630,691 issued to Mueller-Mach et al. is directed to an LED device comprising a phosphor-converting substrate that converts a fraction of the primary light emitted by a light emitting structure of the LED into one or more wavelengths of light that combine with unconverted primary light to produce white light. As shown in Fig.1 of the Patent, LED 2 is disposed on substrate 10 which is a phosphor. As shown in Fig.2 of the Patent, reflective electrode 21 is disposed on the surface of the LED. Some primary light emitted by the LED impinges on reflective electrode 21, which reflects the primary light back through the LED and through the substrate. Some of the primary light propagating into the substrate is converted into yellow light and some is not converted. When the two types of light are emitted by the substrate, they combine to produce white light. Utilizing a reflective electrode improves the efficiency of the LED device by ensuring that the amount of primary light en-

tering the substrate is maximized.

[0010] U.S. Patent Application Publication No. 2002/0030444 filed by Muller-Mach et al., which issued as U.S. Patent No. 6,696,703 to Mueller-Mach et al., is directed to a thin film phosphor-converted LED structure. Fig.2 of the Application shows an LED structure 2 and a phosphor thin film 21 on a surface of LED 2. The LED generates blue light that impinges on phosphor film 21. Some light passes through phosphor 21 and some is absorbed and converted into yellow light which is emitted from phosphor 21. The blue and yellow light combine to form white light. In Fig.3 of the Application, a reflective pad 25 is on a surface of LED 2. Light from LED 2 is reflected by reflective pad 25 back through LED 2 and into phosphor 21. Light is then combined, as shown in Fig.2 of the Patent. Fig.4 of the Patent uses two phosphor films 31, 33 that are separated from LED 2 by substrate 13. Film 31 emits red light. Film 33 emits green light. Blue light emitted by LED 2 passes through films 31, 33, which combines with the red and green light to produce white light. In the embodiment of Fig.5 of the Application, LED device 50 includes a plurality of phosphor thin films 37 and 38. A dielectric mirror 36 is disposed between thin film 37 and substrate 13. The dielectric mirror 36 is fully transparent to the primary emission of light emitting structure 2, but is highly reflective at the wavelength of the emissions of the phosphor thin films 37 and 38. U.S. Patent Application Publication No. 2002/0030060 filed by Okazaki is directed to a white semiconductor light-emitting device provided with an ultraviolet light-emitting element and a phosphor. The phosphor layer has a blue light-emitting phosphor and a yellow light-emitting phosphor, mixedly diffused. The light-emitting device 3 is inside reflective case 5. In Figs. 2, 4, and 8 of the Application, phosphor layer 6 is formed away from light-emitting element 3. In Fig.2 of the Application shows phosphor layer 6 formed inside sealing member 7, which is formed from a translucent resin. In Figs. 4 and 8 of the Application, the phosphor layer is formed on the surface of sealing member 7.

[0011] U.S. Patent Application Publication No. 2002/0218880, filed by Brukilacchio, is directed to an LED white light optical system. As shown in Fig.1 of the Application, optical system 100 includes LED optical source 110, optical filter 120, reflector 130, phosphor layer 135, concentrator 140, a first illumination region 150, a second illumination region 170, and thermal dissipater 190. Optical filter 120 includes a reflected CCT range and a transmitted CCT range. Optical energy that is within the reflected CCT range is prohibited from passing through optical filter 120 (e.g., via reflection). Optical energy that enters the optical filter front face 121 from the phosphor layer back face 137 that is in the reflected range of optical filter 120 is reflected back into phosphor layer 135. Optical energy that is in the transmitted CCT range of optical filter 120 transmits through filter 120 and interacts with reflector 130.

[0012] The reflector 130 is a reflective optical element

positioned to reflect optical energy emitted from the LED optical source back face 112 back into LED optical source 110. The optical energy interacts with the optical material and a portion of the optical energy exits LED front face 111 and interacts with optical filter 120. The optical energy then continues into the phosphor layer, thereby providing a repeating telescoping circular process for the optical energy that emits from the phosphor layer back face 137. This repeating process captures optical energy that otherwise is lost. Concentrator 140 captures optical energy emitting out of the phosphor layer front face 136.

[0013] U.S. Patent Application Publication No. 2002/0003233 filed by Mueller-Mach et al., which issued as U.S. Patent No. 6,501,102 to Mueller-Mach et al., are directed to a LED device that performs phosphor conversion on substantially all of the primary radiation emitted by the light emitting structure of the LED device to produce white light. The LED device includes at least one phosphor-converting element located to receive and absorb substantially all of the primary light emitted by the light-emitting structure. The phosphor-converting element emits secondary light at second and third wavelengths that combine to produce white light. Some embodiments use a reflective electrode on the surface of the light emitting structure and some do not. In embodiments that use a reflective electrode 21 (Figs. 2, 3, 6, 7 of the Application), a substrate separates the light emitting structure from the phosphor layers. That is, the light emitting structure is on one side of the substrate and a phosphor layer is on the other side of the substrate. In embodiments that do not use a reflective electrode (Figs. 4, 5 of the Application), a phosphor layer is disposed on a surface of the light emitting structure.

[0014] U.S. Patent No. 6,686,691 issued to Mueller et al. is directed to a tricolor lamp for the production of white light. The lamp employs a blue LED and a mixture of red and green phosphors for the production of white light. As shown in Fig.3, lamp 20 includes LED 22 which is positioned in reflector cup 28. LED 22 emits light in a pattern indicated by lines 26 and a phosphor mixture 24 is positioned in the pattern. It may be seen that some unabsorbed light emitted by LED 22 reflects from walls of reflector cup 28 back to phosphor mixture 24. Reflector cup 28 may modify light pattern 26, if light is reflected into a space not previously covered by the initial light pattern. The walls of the reflector cup may be parabolic.

[0015] U. S. Patent No. 6,252,254 and 6,580,097, both issued to Soules et al., are directed to an LED or laser diode coated with phosphors. The '097 Patent is a division of the '254 Patent. More particularly, the Patents disclose a blue-emitting LED covered with a phosphor-containing covering. The phosphor-containing covering contains green-emitting phosphors and red-emitting phosphors. The green and red phosphors are excitable by the blue-emitting LED.

[0016] U.S. Patent No. 6,513,949 issued to Marshall et al., U.S. Patent No. 6,692,136 issued to Marshall et al., and U.S. Patent Application Publication No.

2002/0067773 filed by Marshall et al. are directed to an LED/phosphor/LED hybrid lighting system. The '136 Patent is a continuation of the '949 Patent. The '773 Patent Application issued as the '136 Patent. As shown in Fig.1A, LED 10 includes an LED chip mounted in a reflective metal dish or reflector 12 filled with a transparent epoxy 13. Fig.1B schematically depicts a typical phosphor-LED 14 which is substantially identical in construction to the LED of Fig.1A, except that the epoxy 18 filling the reflector 16 contains grains 19 of one or more types of luminescent phosphor materials mixed homogeneously therein. The phosphor grains 19 convert a portion of the light emitted by LED chip 15 to light of a different spectral wavelength. The system permits different lighting system performance parameters to be addressed and optimized as deemed important by varying the color and number of the LEDs and/or the phosphor of the phosphor-LED.

[0017] U.S. Patent No. 6,603,258, issued to Mueller-Mach et al., is directed to a light emitting diode device that produces white light by combining primary bluish-green light with phosphor-converted reddish light. The LED is mounted within a reflector cup that is filled with a phosphor-converting resin. Primary radiation emitted by the LED impinges on the phosphor-converting resin. Part of the primary radiation impinging on the resin is converted into reddish light. An unconverted portion of the primary radiation passes through the resin and combines with the reddish light to produce white light.

[0018] U.S. Patent No. 6,616,862, issued to Srivastava et al., is directed to halophosphate luminescent materials co-activated with europium and manganese ions. Fig.3 of the Patent discloses an LED mounted in cup 120 having a reflective surface 140 adjacent the LED. The embodiment includes a transparent case 160 in which phosphor particles 200 are dispersed. Alternatively, the phosphor mixed with a binder may be applied as a coating over the LED surface. A portion of blue light emitted by the LED that is not absorbed by the phosphor and the broad -spectrum light emitted by the phosphor are combined to provide a white light source.

[0019] U.S. Patent Nos. 6,069,440, 6,614,179, and 6,608,332, issued to Shimazu et al., are directed to a light emitting device comprising a phosphor which converts the wavelength of light emitted by a light emitting component and emits light. These Patents also disclose a display device using multiple light emitting devices arranged in a matrix. These Patents are related because they flow from the same parent application. U.S. Patent No. 6,580,224 issued to Ishii et al. is directed to a backlight for a color liquid crystal display device, a color liquid crystal display device, and an electroluminescent element for a backlight of a color liquid crystal display device.

[0020] U.S. Patent Application Publication No. 2002/0167014 filed by Schlereth et al., which issued as U.S. Patent No. 6,734,467 to Schlereth et al., are directed to an LED white light source having a semiconductor LED based on GaN or InGaN which is at least partly surround-

ed by an encapsulation made of a transparent material. The transparent material contains a converter substance for at least partial wavelength conversion of the light emitted by the LED. The LED has a plurality of light-emitting zones by which a relatively broadband light emission spectrum is generated energetically above the emission spectrum of the converter substance.

[0021] A publication entitled "Optical simulation of light source devices composed of blue LEDs and YAG phosphor" by Yamada K., Y. Imai, and K Ishii, published in Journal of Light and Visual Environment 27(2): 70-74 (2003) discloses using light reflected from a phosphor as an effective way of obtaining high output from light sources composed of LEDs and phosphor.

SUMMARY OF THE INVENTION

[0022] A light emitting apparatus comprises a radiation source for emitting multi-colored radiation. A diffuser material receives at least a portion of the multi-colored radiation emitted by the radiation source and converts the multi-colored radiation into forward transferred radiation and back transferred radiation. An optic device is coupled to the diffuser material and is adapted to receive the back transferred radiation and extract at least a portion of the back transferred radiation from the optic device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The invention is best understood from the following detailed description when read in connection with the accompanying drawing. It is emphasized that, according to common practice, the various features of the drawing are not to scale. On the contrary, the dimensions of the various features are arbitrarily expanded or reduced for clarity. Included in the drawing are the following Figures:

Fig.1 is a graph of relative output versus wavelength showing reflected and transmitted spectral distribution of light for one type of phosphor (YAG:Ce); Fig.2 is a high efficiency light source that uses solid state emitter(s) and down conversion material, in accordance with an exemplary embodiment of the present invention; Fig.2A is an alternative embodiment of a high efficiency light source that uses multiple colored light emitting sources and down conversion material; Fig.2B is a cross-sectional view of a bottom portion of the high efficiency light source shown in Fig.2A; Fig.3 is a cross-sectional view of a bottom portion of the high efficiency light source shown in Fig.2; Fig.4 illustrates another high efficiency light source that uses multiple solid state emitters and down conversion material, in accordance with another exemplary embodiment of the present invention; Fig.5A is yet another embodiment of a high efficiency light source that uses solid state emitter(s) and down

conversion material, in accordance with another exemplary embodiment of the present invention; Fig. 5B is a cross-sectional view of the high efficiency light source shown in Fig. 5A;

Fig. 6 is an illustration of still another high efficiency light source that uses solid state emitter(s) and down conversion material, in accordance with an exemplary embodiment of the present invention;

Fig. 7 depicts a reflector surrounding the high efficiency light source shown in Fig. 6, for redirecting the rays emitted from the light source(s);

Fig. 7A illustrates another exemplary embodiment of the invention using multiple colored light emitting sources; Fig. 7B illustrates a down conversion material dispersed in a down conversion material layer in accordance with an exemplary embodiment of the present invention;

Fig. 7C illustrates a down conversion material dispersed in a down conversion material layer in accordance with an alternative embodiment of the present invention;

Fig. 7D illustrates a down conversion material dispersed in a down conversion material layer in accordance with another alternative embodiment of the present invention;

Figs. 8A through 8E illustrate various geometric shapes for the optical element, or optical lens, disposed immediately above an exemplary light emitting source, in accordance with different exemplary embodiments of the present invention;

Figs. 8F and 8G illustrate other embodiments of a reflector and an optic device;

Fig. 9A shows a device having multiple high-efficiency light sources that use solid state emitter(s) and down conversion material placed on a lightpipe for redirecting the light rays from the light sources, in accordance with an exemplary embodiment of the present invention;

Fig. 9B is a cross-sectional view of the device shown in Fig. 9A; Fig. 9C illustrates a cross-section view of another alternative embodiment of the device shown in Fig. 9A that may include multiple colored light emitting sources;

Fig. 10A is an illustration of another device having multiple high efficiency light sources that use solid state emitter(s) and down conversion material disposed around edges of a lightpipe for redirecting the light rays from the light sources, in accordance with an exemplary embodiment of the present invention;

Fig. 10B is a cross-sectional view of the device shown in Fig. 10A; Fig. 11 is an illustration of yet another high efficiency light source arranged so that it is surrounded by a reflector and a high efficiency microlens diffuser, in accordance with an exemplary embodiment of the present invention;

Fig. 11A is an illustration of an alternative embodiment of the embodiment illustrated in Fig. 11 that may include multiple colored light emitting sources;

Fig. 12 is an illustration of still another high efficiency light source directing radiation towards a down conversion material and a reflector, where the down conversion material is disposed between the high efficiency light source and the reflector, in accordance with an exemplary embodiment of the present invention;

Fig. 12A is an illustration of an alternative embodiment of the embodiment illustrated in Fig. 12 that may include multiple colored light emitting sources;

Fig. 13 is a schematic diagram depicting a high powered light emitter radiating light towards a down conversion material by way of an optical element, in accordance with an exemplary embodiment of the present invention; and

Fig. 14 is a diagram illustrating the exemplary radiation rays that may result when an exemplary radiation ray from a short-wavelength LED chip impinges on a layer of down conversion material.

DETAILED DESCRIPTION OF THE INVENTION

[0024] Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention.

[0025] Fig. 14 is a diagram illustrating the exemplary radiation rays that may result when an exemplary radiation ray 2000 from a short-wavelength LED chip 2002 impinges on a layer of down conversion material 2004 which may be a phosphor layer. The impingement of exemplary short-wavelength radiation 2000 from a short-wavelength source such as an LED chip 2002 onto a down conversion material layer 2004 may produce radiation with four components: back transferred short-wavelength radiation 2006 reflected from the down conversion material layer 2004; forward transferred short-wavelength radiation 2008 transmitted through the down conversion material layer 2004; forward transferred down-converted radiation 2010 transmitted through the down conversion material 2004; and back transferred down-converted radiation 2012 reflected from the down conversion material 2004. The four components may combine to produce white light.

[0026] Two of the four components 2010 and 2012 may each be comprised of two sub-components. One of the sub-components of forward transferred down-converted radiation may be emitted radiation 2014; i.e., down-converted radiation having a longer wavelength than the short-wavelength radiation that impinges onto the down conversion material layer 2004. The emitted radiation sub-component 2014 of forward transferred down-converted radiation may be produced by short-wavelength radiation 2000 impinging on particles of the down conversion material 2004 as it is transmitted through the down conversion material 2004. The second sub-com-

ponent of forward transferred down-converted radiation may be forward scattered emitted radiation 2016; i.e., other down-converted radiation having a longer wavelength than the short-wavelength radiation 2000 that impinges onto the down conversion material layer 2004. The forward scattered emitted radiation sub-component 2016 of forward transferred down-converted radiation 2010 may be produced by short-wavelength radiation 2000 impinging on particles of the down conversion material 2004 and that also bounces back and forth on the particles of the down conversion material 2004 before being transmitted through the down conversion material 2004.

[0027] One of the sub-components of back transferred down-converted radiation 2012 may be emitted radiation 2020; i.e., down-converted radiation having a longer wavelength than the short-wavelength radiation 2000 that impinges onto the down conversion material layer 2004. The emitted radiation sub-component 2018 of back transferred down-converted radiation 2012 may be produced by short-wavelength radiation 2000 impinging on particles of the down conversion material 2004 as it is reflected from the down conversion material 2004. The second sub-component of back transferred down-converted radiation 2012 may be back scattered emitted radiation 2020; i.e., other down-converted radiation having a longer wavelength than the short-wavelength radiation 2000 that impinges onto the down conversion material layer 2004. The back scattered emitted radiation sub-component 2020 of back transferred down-converted radiation 2012 may be produced by short-wavelength radiation 2000 impinging on particles of the down conversion material 2004 and that also bounces back and forth on the particles of down conversion material 2004 before being reflected from the down conversion material 2004.

[0028] White light may be produced by the combinations of the various components discussed above. In the forward transferred direction (i.e., for radiation 2008, 2014, 2016, 2010 that is transmitted through the down conversion material layer), white light may be produced by the combination of forward transferred short-wavelength radiation 2008 with either or both of the sub-components 2014, 2016 of the forward transferred down-converted radiation 2010. That is, white light may be produced in the forward transferred direction by the combination of forward transferred short-wavelength light 2008 with transmitted emitted radiation 2014 and/or with transmitted forward scattered emitted radiation 2016.

[0029] In the back transferred direction (i.e., for radiation 2006, 2018, 2020, 2012 that is reflected from the down conversion material layer), white light may be produced by the combination of back transferred short-wavelength radiation 2006 with either or both of the sub-components 2018, 2020 of the back transferred down-converted radiation 2012. That is, white light may be produced in the back transferred direction by the combination of back transferred short-wavelength light 2006 with reflected emitted radiation 2018 and/or with reflected

back scattered emitted radiation 2020.

[0030] The wavelength of the forward transferred short-wavelength radiation 2008 may be about the same as the wavelength of the radiation 2000 emitted by a radiation source such as an LED chip 2002. The wavelength of the back transferred short wavelength radiation 2006 may be about the same as the wavelength of the radiation 2000 emitted by the radiation source 2002. The wavelength of the forward transferred short-wavelength radiation 2008 may be about the same as the wavelength of the back transferred short-wavelength radiation 2006. In an exemplary embodiment, the radiation source 2002 may emit radiation exhibiting a wavelength that is less than 550 nm, more particularly in a range of about 200 nm to less than 550 nm. Accordingly, the wavelength of the forward transferred short-wavelength radiation 2008 and the wavelength of the back transferred short-wavelength radiation 2006 may be less than 550 nm, more particularly in a range of about 200 nm to less than 550 nm.

[0031] The wavelength of the forward transferred down-converted radiation 2010 (including its sub-components 2014, 2016) and the wavelength of the back transferred down-converted radiation 2012 (including its sub-components 2018, 2020) may be any wavelength that is longer than the excitation spectrum of the down conversion material 2004. In an exemplary embodiment, the excitation spectrum of the down conversion material 2004 may be in the range of about 300 nm to about 550 nm. In alternative embodiments, other down conversion materials may be used that have an excitation spectrum other than in the range of about 300 nm to about 550 nm. The excitation spectrum of the down conversion material 2004 should produce radiation having a wavelength that is longer than the wavelength of the radiation produced by the short-wavelength emitting radiation source 2002. In an exemplary embodiment, the down conversion material 2004 may produce radiation in the range of from about 490 nm to about 750 nm.

[0032] However, if the LED chip 2002 does not emit short-wavelength radiation, or if the wavelength of radiation emitted by the LED chip is greater than the excitation spectrum of the down-conversion material, the down-conversion material layer 2004 behaves like a diffuser element. Therefore, only two components may be produced by the down conversion material 2004: forward transferred radiation 2008 transmitted through the down-conversion material 2004, and back transferred radiation 2006 reflected from the down-conversion material 2004.

[0033] The inventors have discovered that the performance of phosphor converted LEDs is negatively affected when placing the down-conversion phosphor close to the LED die. Poor performance is mainly due to the fact that the phosphor medium surrounding the die behaves like an isotropic emitter, and some portion of the back transferred radiation towards the die circulates between the phosphor layer, the die, and the reflector cup. As a result, the back transferred radiation increases

the junction temperature, thus reducing system efficacy and increasing the yellowing of the encapsulant. All of these factors reduce the light output over time.

[0034] The literature shows that 60 percent of the light impinging on the phosphor layer is back transferred, contributing to the described effects (Yamada, et al., 2003). Lab measurements of eight YAG:Ce phosphor plates proved that nearly 60% of the radiant energy is transferred back in the direction of the blue LED source. The absolute magnitude of the radiant energy reflected depends, among other factors, on the density of the phosphor coating. Fig.1 shows the measured reflected spectral power distribution 2 of a blue LED with a YAG:Ce phosphor plate. Fig.1 also shows the measured transmitted spectral power distribution 4 of the same arrangement. As shown, most of the light is reflected back and not transmitted forwardly.

[0035] Such effects are expected to be of a higher magnitude in RCLEDs, because their light output is much more collimated. Consequently, the packaging attempts to capture the transmitted, emitted, and reflected components to improve system efficiency. Additionally, the inventors have created packaging that allows the phosphor layer to be moved away from the die, preventing radiation feedback into the LED and RCLED. As a result, the packaging increases the efficiency of the device by allowing more of the radiation reflected off and emitted by the phosphor layer to exit the device.. At the same time, radiation from the RCLED impinges on the phosphor layer uniformly to obtain a uniform white light source. In addition, the life of the LED and RCLED is improved

[0036] In traditional phosphor-converted white LEDs, where the phosphor is placed adjacent the die, more than 65% of the light generated by the phosphor is back-scattered and lost within the LED package. Based on these findings, a technique referred to as Scattered Photon Extraction™ (SPE™) has been developed. An aspect of the technique has been disclosed in pending International Application No. PCT/US2005/015736 filed on May 5, 2005 and published as WO 2005/107420 A2 on November 17, 2005.

[0037] To increase the light output from a phosphor-converted white LED (pc-LED) and to achieve higher luminous efficacy, the down-conversion material (e.g., phosphor or quantum dots) is removed to a remote location and a properly tailored optic device is placed between the LED chip and the down-conversion material layer. Then, the back transferred light can be extracted to increase the overall light output and efficacy. This technique significantly increases the overall light output and luminous efficacy of a pc-white LED by extracting the phosphor emitted and back scattered reflected radiation, and the reflected short-wavelength radiation that otherwise would be lost.

[0038] Figs. 2 and 3 illustrate a first exemplary embodiment of the invention using the SPE™ concept. Fig.2 illustrates a high efficiency light source that uses solid state emitter(s) and down conversion material, in accord-

ance with an exemplary embodiment of the present invention.

[0039] This embodiment has a distributing optic, light transmissive, enclosure optic 10, which has a cylindrical geometry. As shown, enclosure optic 10 includes phosphor layer 12 embedded in the middle section of the distributing optic. This configuration effectively splits the distributing optic into substantially two equal pieces, or portions. That is, the phosphor layer may be a strip that is substantially parallel to a longitudinal axis of cylindrical optic 10.

[0040] In one exemplary embodiment, phosphor layer 12 may be a YAG:Ce phosphor layer. In an alternative exemplary embodiment, the phosphor layer may comprise other phosphors, quantum dots, quantum dot crystals, quantum dot nano crystals or other down conversion material. It will be understood that other embodiments of the present invention may include a phosphor layer that is similar to phosphor layer 12. Unlike the embedded phosphor layer, shown in Fig.2, however, other embodiments may have a phosphor layer that is not embedded. Moreover, the phosphor layer need not be of uniform thickness, rather it may be of different thicknesses or different phosphor mixes to create a more uniform color output.

[0041] One or more LEDs or RCLEDs may be placed inside the cylindrical optic at a bottom portion, designated as 14. In an alternative embodiment, one or more LEDs/RCLEDs may be placed at a location other than at the bottom portion of the cylindrical optic.

[0042] Short wavelength radiation 16 is emitted from the LEDs/RCLEDs. Short wavelength radiation is in the range of 250 nm to 500 nm. Because phosphor layer 12 is substantially in the middle of the cylindrical optic, short-wavelength radiation from the LEDs/RCLEDs causes short-wavelength radiation to impinge from either side of the cylindrical optic onto the phosphor layer 12. The impingement of short-wavelength radiation onto the phosphor layer 12 may produce radiation with four components: short-wavelength radiation 18, back transferred from the phosphor layer 12; short-wavelength radiation 20, forward transferred through the phosphor layer 12; down-converted radiation 22, back transferred from the phosphor layer 12; and down-converted radiation 24, forward transferred through the phosphor layer 12. These four components, which are produced on both sides of the phosphor layer 12, combine and produce white light 26. By using the light transmissive properties of the cylindrical optic 10, the back transferred short-wavelength radiation from the phosphor layer 12 and the down-converted radiation back transferred from the phosphor layer 12 may be extracted. Therefore, the overall light output and efficacy of a phosphor-converted white LED device is significantly increased.

[0043] As an example, a high-flux blue (470nm) illuminator LED (Shark series) emitter by Opto Technology may be used. The density of phosphor layer 12 may be in the range of 4-8 mg/cm² (other densities are also con-

templated), the length of cylindrical optic 10 may be in the range of 2 to 4 inches, and the diameter of the cylindrical optic may be about 0.5 inches. As another example, a different package efficiency and uniformity may be achieved by changing the phosphor-layer density, and the length and diameter of the cylindrical optic. Better efficiency and uniformity of light along the circumference of the cylindrical optic may be achieved when the cylindrical optic is 2.25 inches long.

[0044] The embodiment shown in Fig.2 may be formed from half-round acrylic rod segments that are cut from a fully-round acrylic rod and polished. Phosphor may be mixed with optically clear epoxy and then spread uniformly on the flat surface of each rod segment. The rod segments may then be attached together and put into an oven to cure the epoxy.

[0045] The overall emission loss for a 2.25 inch optical element (cylindrical optic) was found to be approximately 16%. The losses included: 6% light reflected back to the LED, 7% Fresnel loss, and 3% irrecoverable loss due to mounting hardware.

[0046] Approximately half of the losses may be attributed to the Fresnel loss, which occurs at the boundaries between media having different refractive indices. Fresnel losses may be reduced by using a coupling mechanism between the LEDs/RCLEDs and the cylindrical optic. In addition, losses may be recovered by using an anti-reflective coating on the LEDs/RCLEDs to prevent light from reflecting back to the LEDs/RCLEDs.

[0047] Fig.3 is a cross-sectional view of the cylindrical optic, at the bottom portion, designated as 14. As shown, cylindrical optic 10 includes two half-round acrylic rod segments 14a and 14b. Phosphor layer 12 is sandwiched between acrylic rod segment 14a and acrylic rod segment 14b. Each acrylic rod segment includes short wavelength radiation emitting sources 17 and 19. Short wavelength radiation emitting sources 17 and 19 may each be a semiconductor short wavelength radiation emitting diode, such as a light emitting diode (LED), a laser diode (LD), or a resonant cavity LED (RCLED). It will be understood that one or more than two light emitting sources may be included in bottom portion 14. As such, there may be an array of multiple light emitters disposed within acrylic rod segment 14a and another array of multiple light emitters disposed within acrylic rod segment 14b. These arrays may be arranged symmetrically with respect to each other, in a manner that is similar to light sources 17 and 19, which are shown disposed symmetrically about phosphor layer 12 of Fig.3.

[0048] Figs. 2A and 2B illustrate another embodiment of the present invention having the distributing optic, light transmissive enclosure 10. Fig.2A is an alternative embodiment of a high efficiency light source that uses multiple colored light emitting sources and down conversion material. Fig.2B is a cross-sectional view of a bottom portion of the high efficiency light source shown in Fig.2A.

[0049] In one exemplary embodiment, down conversion material 12 may be sandwiched between two diffus-

er layers 20 and 22. The embodiment illustrated in these figures also uses the SPE™ technique. In this embodiment, and in all embodiments disclosed herein, the down conversion material 12 may comprise one or more phosphors such as YAG:Ce; YAG:ce phosphor plus Eu phosphor; YAG:Ce phosphor plus cadmium-selenide (CdSe); or other types of quantum dots created from other materials including lead (Pb) and Silicon (Si); and other phosphors that have been identified in a copending PCT application filed on June 20, 2006 (Attorney Docket RPI-143WO). In other alternative embodiments, the phosphor layer may comprise other phosphors, quantum dots, quantum dot crystals, quantum dot nano crystals, or other down-conversion materials. In any embodiment or alternative embodiment, the down conversion region may be a down conversion crystal instead of a powdered material mixed into a binding medium.

[0050] One or both of the diffuser layers 20, 22 may be a microlens layer or micro or nano scattering particles diffused in polymer or other material having the characteristics of beam control for the forward transferred and back transferred radiation. Both the phosphor layer 12 and the diffuser layers 20 and 22 may be embedded in the middle section of the distributing optic 10, as if splitting the distributing optic 10 into substantially two equal pieces, or portions. That is, the phosphor layer 12 and the diffuser layers 20, 22 may be substantially parallel to a longitudinal axis of the distributing optic 10. In an alternative embodiment, neither the phosphor layer 12 nor the diffuser layers 20, 22 need to be embedded. In an exemplary embodiment, the phosphor layer 12 may be bonded to the diffuser layers 20, 22. In an alternative embodiment, the phosphor layer 12 need not be bonded to the diffuser layers 20, 22.

[0051] Phosphor layer 12 and diffuser layers 20, 22 need not have the rectangular shape illustrated in Figs. 2A and 2B. In alternative embodiments, the diffuser layers 20, 22 may be curved, round, square, triangular, or other shapes. In addition, their shapes may change along the longitudinal axis of the distributive optic 10. Furthermore, the respective sizes (respective lengths or widths) of the phosphor layer 12 and the diffuser layers 20, 22 need not be the same. For example, the length or width of the phosphor layer 12 may be different than one or both of the diffuser layers 20, 22.

[0052] In yet another alternative embodiment, a single diffuser layer may be disposed in between two phosphor layers. In still another alternative embodiment, a diffuser layer may be disposed in the distributing optic without any phosphor layer.

[0053] A radiation source 24 may comprise a plurality of light emitting sources that may emit multiple color radiation. That is, each of the plurality of light emitting sources may exhibit a spectrum that is different from a spectrum of at least one of the other light emitting sources. Each of the light emitting sources 24 may be one or more LEDs, or one or more LDs (laser diode), or one or more RCLEDs. Any of the embodiments described herein may

be one or more of these types of diodes. The plurality of multiple colored light emitting sources 24 may be mounted on a board or substrate 14 so that the LEDs 24 are disposed within the confines of the distributing optic 10 when the distributing optic 10 is mounted on the board 14. That is, the multicolored LEDs 24 may be placed on board 14 so that they are inside the distributing optic 10 when the bottom of the distributing optic 10 is mounted on board 14.

[0054] In this exemplary embodiment, and in all of the embodiments disclosed in this application, individual ones of the LEDs 24 may exhibit one or more of the colors red, green, and blue. For example, if three LEDs are used in this embodiment, one LED may emit red light, a second LED may emit green light, and the third LED may emit blue light. That is, each of the LEDs (sometimes referred to as chips) may produce its own respective narrow band of radiation, or may produce both narrow bands and wide bands of radiation. In an alternative embodiment, one or more of the LEDs may display a color other than red, green, or blue. Although Figs. 2A and 2B illustrate three LEDs, alternative embodiments may use fewer or more LEDs. In addition, the number of LEDs placed on each side of the phosphor layer 12 may be the same or may be different. All of the embodiments of the device may mix multiple spectra to create white light or may create various shades of colors with uniform illumination and color without reducing the overall luminous efficiency.

[0055] The colors that may be displayed by the LEDs in any embodiment may depend upon the use to which the device is put. In some embodiments, multiple colors may be used. In other embodiments, only two colors may be used. In some embodiments more than one LED may emit a particular color. Even if the multiple colored light emitting sources 24 are capable of emitting a plurality of colors, all of the colors need not be emitted in every embodiment. Instead, only some of the colors may be emitted in a particular embodiment or the hue of a particular color may be modified in ways that are known to one of ordinary skill in the art. The use of LEDs emitting different colors and the use of techniques that may modify the hue of one or more colors may enable one to dynamically change the emitted colors based upon a user's needs.

[0056] As illustrated in Fig.2B, some of the multiple colored light emitting sources 24 may be placed adjacent a first side 12A of the phosphor layer 12 and others of the multi-colored LEDs 24 may be placed adjacent a second side 12B of the phosphor layer 12. Each of the multiple colored light emitting sources 24 may be placed at one or more predetermined distances from the phosphor layer 12.

[0057] In an alternative embodiment of Figs. 2A and 2B, the multiple colored radiation emitting sources 24 may be placed at a location other than on board 14 or may be placed at a location other than at the bottom of the distribution optic 10. In another alternative embodiment, multi-colored LEDs may be placed adjacent both ends 15, 16 of the distributing optic 10. In yet other alter-

native embodiments, the phosphor layer 12 may be used without one or more of the diffuser layers 20, 22 or one or more of the diffuser layers 20, 22 may be used without phosphor layer 12.

[0058] Fig.4 illustrates another exemplary embodiment of the invention using the SPE™ technique. It illustrates another high efficiency light source that may use multiple solid state emitters and down conversion material. This embodiment may be used in interior spaces where general ambient lighting is required. As shown, the device includes phosphor plate 50 (for example YAG:Ce or other phosphors, as enumerated previously). The device also includes multiple semiconductor short wavelength radiation emitting diodes 56 forming an array, such as LED/RCLED array 52. The array 52 is mounted on substrate 54 that may be of aluminum material. In an exemplary embodiment, substrate 54 may be circular. In the exemplary configuration illustrated in Fig.4, the LEDs/RCLEDs are arranged in a spaced relation to each other and placed around the circular substrate.

[0059] The array of short wavelength radiation emitting diodes are placed on the substrate so that the radiation emitting surfaces of the diodes face toward phosphor layer plate 50. In this manner, diodes 56 emit short wavelength radiation toward phosphor layer plate 50. As the short wavelength radiation impinges on the phosphor layer plate, the four components of radiation discussed above may be produced: short wavelength back transferred radiation and back transferred down-converted radiation 60; and short wavelength forward transferred radiation and forward transferred down-converted radiation 64. The short wavelength back transferred radiation and back transferred down converted radiation 60 produces white light 62. The forward transferred short wavelength radiation and forward transferred down-converted radiation 64 produces white light 66.

[0060] Figs. 5A and 5B illustrate another exemplary embodiment of the invention using the SPE™ technique. It is another embodiment of a high efficiency light source that uses solid state emitter(s) and down conversion material. Fig.5B is a cross-sectional view of the high efficiency light source shown in Fig.5A. As shown, device 500 includes cup 502, and one or more light emitters 501 disposed within cup 502 at a base of cup 502. Also included are phosphor layers 503 and 504. Phosphor layer 504 is disposed at the opposite end from the base of light emitter 501 and at a substantial center from the walls of cup 502. Phosphor layer 503 is deposited on the inside of the walls of cup 502. The embodiment shown in Figs. 5A and 5B may be used in interior spaces where general ambient lighting is required.

[0061] The device 500 includes cup 502 which may be a transparent cup having one LED/RCLED or multiple LEDs/RCLEDs emitting short wavelength radiation arranged in an array. The cup includes one phosphor layer 503 bonded to the inside transparent wall of cup 502. The other phosphor layer 504 may be bonded only at the center area of the cup. Accordingly, most of the back

transferred short wavelength radiation and back transferred down-converted radiation may exit directly from the transparent portion of the front surface. Narrow beams of emitted light from the LED/RCLED are preferred in this embodiment to minimize short wavelength radiation from the LED/RCLED directly exiting the transparent portion of the front surface without impinging on the phosphor layer. The cup may be made of glass or acrylic.

[0062] The inside portion of cup 502 may be filled with glass or acrylic material, thereby sandwiching phosphor layer 503 between cup 502 and the inside portion contained within cup 502. Phosphor layer 504 may also be bonded onto the exterior surface of the glass or acrylic material. In an alternate embodiment, phosphor layer 504 may be placed within the glass or acrylic material, in a manner similar to that described for the phosphor layer sandwiched between two half-round acrylic rods, shown in Figs. 2 and 3.

[0063] Fig.6 illustrates yet another exemplary embodiment of the invention using the SPE™ technique. It illustrates another high efficiency light source that uses solid state emitter(s) and down conversion material. It illustrates an optic device making use of a down conversion material that is remote from a short wavelength radiation emitter. The down conversion material may be a phosphor. As shown, device 600 includes short wavelength radiation emitter 602 separated from phosphor layer 604 by optic device 606 which may be made of a substantially transparent medium that may be substantially light transmissive. In an exemplary embodiment, the substantially transparent medium may be air. In an alternative embodiment, the substantially transparent medium may be glass or acrylic. Phosphor (or quantum dot) layer 604 may be mounted or deposited on a portion of optic device 606 having substantially transparent and substantially light transmissive walls 610 and 612. Phosphor (or quantum dot) layer 604 may include additional scattering particles (such as micro spheres) to improve mixing light of different wavelengths. Also, the phosphor (or quantum dot) layer 604 may be of single phosphor (or quantum dot) or multiple phosphors (or quantum dots) to produce different colored down-converted radiation that may be in several different spectral regions. Alternatively, a layer with scattering particles only may be placed above, or below, or above and below the down conversion material layer to improve color mixing.

[0064] In an exemplary embodiment, the portion of optic device 606 upon which phosphor layer 604 may be deposited may be an end 618 of optic device 606. Radiation emitter 602 may be located at another portion of optic device 606. In an exemplary embodiment, radiation emitter 602 may be located at another end 620 of optic device 606. Each of walls 610 and 612 of optic device 606 may be a continuous wall, if optic device 606 has a circular cross-section.

[0065] Short wavelength radiation emitter 602 may be located between walls 610 and 612. Both the short wave-

length radiation emitter 602 and the optic device 606 may be positioned on a base 603. Radiation rays 614 may comprise radiation transmitted through phosphor layer 604 including forward transferred short-wavelength radiation transmitted through the phosphor layer 604 and forward down-converted radiation transmitted through the phosphor layer 604.

[0066] Exemplary radiation rays 615 may comprise back transferred short-wavelength radiation and back transferred down-converted reflected radiation that may be emitted and/or scattered back by phosphor layer 604. Radiation rays 616 may comprise the radiation scattered back by phosphor layer 604. Radiation rays 616 may comprise the radiation rays 615 that may be transmitted through the substantially transparent, substantially light transmissive walls 610 and 612. Although exemplary arrows 615 show back transferred radiation being transferred around the middle of side walls 610 and 612, it will be understood that back transferred radiation may be transferred through side walls 610 and 612 at multiple locations along the side walls 610 and 612. The transfer of radiation outside the optic device 606 may be referred to as extraction of light. Accordingly, both radiation rays 615 and radiation rays 616 may include short-wavelength radiation reflected from the phosphor layer 604 and down-converted reflected radiation that may be emitted and/or scattered from the phosphor layer 604. Radiation rays 616 may also include radiation from radiation emitter 602. In an exemplary embodiment, some or all of radiation rays 615 and/or 616 may be seen as visible light.

[0067] The transfer (extraction) of radiation through side walls 610 and 612 to the outside of optic device 606 may occur because optic device 606 may be configured and designed with substantially transparent, substantially light transmissive walls 610 and 612 to extract radiation from inside optic device 606 to outside optic device 606. In addition, various widths of optic device 606 may be varied in order to extract a desired amount of radiation out of the optic device 606. The widths that may be varied are the width at the end 618 and the width at the end 620. Similarly, widths of optic device between end 618 and end 620 may be varied. The variation of widths of optic device 606 between ends 618 and 620 may be effected by walls 610 and 612 being substantially straight, curved, or having both straight and curved portions.

[0068] The dimensions of the features of the optic device 606 discussed above may be varied depending upon the application to which the optic device 606 may be used. The dimensions of the features of optic device 606 may be varied, and set, by using the principles of ray tracing and the principles of total internal reflection (TIR). When principles of TIR are applied, reflectivity of radiation off of one or both of walls 610 and 612 may exceed 99.9%. The principles of TIR may be applied to all of the embodiments disclosed in this application.

[0069] In one embodiment of optic device 606, for example, the dimensions of optic device 606 may be set in order to maximize the amount of the radiation from radi-

ation source 602 that enters into optic device 606. In another embodiment, the dimensions of optic device 606 may be set in order to maximize the amount of radiation from radiation source 602 that impinges upon down conversion material 604. In yet another embodiment, the dimensions of optic device 606 may be set in order to maximize the amount of radiation that is back transferred from down conversion material 604. In still another embodiment, the dimensions of optic device 606 may be set in order to maximize the amount of radiation that is extracted through walls 610 and 612. In another embodiment, the dimensions of optic device 606 may be set in order to provide a device that, to the extent possible, simultaneously maximizes each of the radiation features discussed above: the amount of radiation entering into optic device 606; the amount of radiation that impinges upon down conversion material 604; the amount of radiation that is back transferred from down conversion material 604; and the amount of radiation that is extracted through walls 610 and 612. In still another embodiment, the dimensions of optic device 606 may be set so that any or all of the features discussed above are not maximized. The principles of ray tracing and the principles of TIR may be used in order to implement any of these embodiments.

[0070] The principles discussed with respect to the embodiment illustrated in Fig.6 may also be applied to all of the embodiments illustrated and discussed herein.

[0071] As indicated above, radiation source 602 may be an LED, an RCLED, or a laser diode (LD). If an LD is used as radiation source 602, all of the radiation from the LD may directed to, and may impinge upon, the down conversion layer 604. Accordingly, when an LD is used, the shape of the optic device 606 may be in the shape of a cylinder because substantially none of the back transferred radiation may bounce back toward the LD and substantially all of the back transferred radiation may be extracted through the sides of the cylinder.

[0072] Fig.7 illustrates yet another exemplary embodiment of the invention using the SPE™ technique. Fig.7 depicts a reflector at least partially surrounding the high efficiency light source shown in Fig.6, for redirecting the rays emitted from the light source(s). As shown, device 700 includes device 600 disposed within reflector 702. Reflector 702 has a geometric shape of a parabola for illustration purposes. The invention is not so limited in that reflector 702 may have other geometrical shapes, such as a cone, a sphere, a hyperbola, an ellipse, a pyramid, or may be box-shaped, for example. Advantages of device 700 may include better control of the beam output distribution and better uniform output of the color. Whenever a reflector is illustrated in any of the embodiments disclosed herein, the shape of the reflector may be any of these shapes.

[0073] Substrate 603 may be used for mounting the short wavelength radiation emitting source (602), one end of optic 606, and one end of reflector 702, as shown in Figs. 6 and 7.

[0074] Light rays 616 may impinge on reflector 702 which may redirect them forward as light rays 714. Advantageously, the direction of light rays 714 are desirably generally in the same direction as radiation rays that may be transmitted through the phosphor layer. Consequently, the total light output of the device 700 may be a combination of radiation transmitted through the phosphor layer and light rays 714. As indicated in the discussion of the embodiment illustrated in Fig.6, the principles of TIR may also be applied to the embodiment illustrated in Fig.7. Light that escapes from optic device 606 may be captured by reflector 702. Some of the light captured by reflector 702 may be redirected by reflector 702 in the direction generally indicated by arrow 714 and some of the light may be redirected back into optic device 606. The effects described herein of combining the principles of TIR with the use of a reflector may apply to all embodiments illustrated in this application that use a reflector.

[0075] Similar to the other embodiments of the invention, short wavelength radiation emitting source 602 may be one or multiple semiconductor short wavelength radiation emitting diodes, such as an LED, LD or RCLED. The short wavelength radiation emitting diodes may be mounted in an array of diodes, similar to the array of light sources depicted as array 52 in Fig.4. In addition, phosphor layer 604 may be similar to phosphor layer 50 depicted in Fig.4.

[0076] Fig.7A illustrates another exemplary embodiment of the invention using the SPE™ technique. The exemplary embodiment illustrated in Fig.7A uses multiple colored radiation emitting sources. As shown, device 710 includes optic device 704 disposed within reflector 702. Optic device 704 may have substantially transparent walls 707 and 708. Down conversion material layer 706 and diffuser layer 705 may be mounted or deposited on a portion of optic device 704 that may be an end 714 of optic device 704. Reflector 702 may be used to control the output beam distribution of the device 710 as well as to achieve uniform color output from the device 710. Optic device 704 and reflector 702 may both be mounted onto substrate 703. Substrate 703 may provide an electrical connection and/or heat dissipation for light sources. In an alternative embodiment, optic device 704 may be used without reflector 702.

[0077] The embodiment illustrated in Fig.7A may have multiple colored radiation emitting sources 701. The nature of the multiple colored radiation emitting sources 701 may be the same as described elsewhere in this application with respect to other embodiments of this invention. The multiple colored radiation emitting sources 701 may be located on a portion of the optic device 704 that may be at an end 712 of the optic device 704. As stated, down conversion material layer 706 and a diffuser layer 705 may be located at another end 714 of the optic device 704. The characteristics of the down conversion material layer 706, the characteristics of the diffuser layer 705, and the number of layers comprising the down conversion material layer 706 and the diffuser layer 705 may

be the same as described elsewhere in this application with respect to other embodiments of this invention. As described elsewhere in this application, for example, the down conversion material layer 706 may be a phosphor layer. The optic device 704 may be a substantially transparent medium or other medium described elsewhere in this application with respect to other embodiments of this invention. For example, optic device 704 may be made of glass, or acrylic, or polymer, or silicon or any other material that is substantially light transmissive.

[0078] It will be understood by those skilled in the art that phosphor layer 706 may also affect light in the same way that a diffuser layer affects light by providing uniformity to the light. That is, phosphor layer 706 may also function as a diffuser. The additional diffuser layer 705 therefore may make the light more uniform than the light may be if a phosphor layer 706 is used alone. In other embodiments, the positions of the phosphor layer 706 and the diffuser layer 705 can be switched. That is, phosphor layer 706 may be located on top of the optic device 704 and diffuser layer 705 may be located on top of the phosphor layer 706. In yet another embodiment, phosphor layer 706 may be used without diffuser layer 705. In still another embodiment, diffuser layer 705 may be used without phosphor layer 706. Regardless of whether a phosphor is used alone, a diffuser is used alone, or both a phosphor and a diffuser are used together, the purpose of using one or both of them may be to provide uniformity to the light and uniformity to any colors that may be emitted by the radiation emitting sources 701.

[0079] Figs 7B-7D illustrate different ways of dispersing the down conversion material 706 used in the embodiment illustrated in Fig.7A and with all of the other embodiments illustrated herein. As illustrated in Fig.7B, down conversion materials such as phosphor may be uniformly dispersed within the down conversion material layer 706.

[0080] As illustrated in Fig.7C, the down conversion material layer 706 may comprise a plurality of down conversion materials. Each one of the plurality of down conversion materials may have different densities of down conversion materials depending on the distance from the center of the layer of down conversion material. For example, down conversion material layer 706 may have four segments, each of the segments have a different density. A first segment of down conversion material 706A having a first density of down conversion material may be at the center of the down conversion material layer 706. A second segment of down conversion material 706B having a second density of down conversion material may surround the first segment of down conversion material 706A. A third segment of down conversion material 706C having a third density of down conversion material may surround the second segment of down conversion material 706B. A fourth segment of down conversion material 706D having a fourth density of down conversion material may surround the third segment of down conversion material 706C. Although each of the

aforesaid segments of down conversion material are shown as having a circular shape, each of the segments may each have different shapes. For example, they could be in the shape of a square, a triangle, or other polygonal shape or any shape other than polygonal. In addition, more or fewer segments of down conversion material may be used.

[0081] A different way of dispersing down conversion material is illustrated in Fig.7D. As shown in Fig.7D, specs or "sesame dots" (that is, small pieces) of down conversion material may be dispersed about the secondary optic device. For example, the specs of down conversion material may be deposited on top of the secondary optic device 708 or may be embedded within the top surface at end 714 of the secondary optic device 704. The specs of down conversion material may be randomly dispersed or may be dispersed in a predetermined pattern.

[0082] The embodiments of a phosphor disclosed in Figs. 7B to 7D along with other embodiments of phosphors discussed elsewhere in this application may be used to adjust phosphor density in order to obtain a desired color and hue. Such adjustments may be made with any embodiment disclosed in this application whether the embodiment is intended to produce white light or light of a particular color. For example, an embodiment may use a mixture of blue and yellow phosphors. An alternative embodiment may use a mixture of multiple kinds of phosphors such as quantum dots, quantum dot crystals, and quantum dot nano crystals. Still other embodiments may use a blue LED either with a single phosphor or a blue LED with multiple phosphors in order to obtain different tones of white light. Still other embodiments may use multiple color LEDs with a diffuser. Additional embodiments may use any combination of these features.

[0083] As indicated elsewhere in this application, respective ones of the radiation emitting sources 701 may emit blue light, green light, or red light in any combination. Different hues of each color may also be used. If one or more of the radiation emitting sources 701 emits blue light, and if the layer 706 is a phosphor, the blue light may be down converted as described elsewhere in this application resulting in the four components of radiation described elsewhere in this application. If one or more of the radiation emitting sources 701 emits blue light, and if the layer 706 is not a phosphor but is a different kind of diffuser material, the blue light impinging on the layer 706 may not be down converted. If one or more of the radiation emitting sources 701 emits red light or emits green light, or emits light of any color other than blue, such light may not be down converted whether layer 706 is a phosphor material or other diffuser material. If blue light, green light, and red light all impinge on layer 706 when a phosphor is used, white light may result depending upon the density of the phosphor.

[0084] Regardless of what colors are respectively emitted by the radiation emitting sources 701, and regardless of whether a phosphor or another diffuser ma-

material is used, when light from the radiation emitting sources 701 impinges on the phosphor or other diffuser material, forward transferred radiation and back transferred radiation results. In the case of blue light impinging on a phosphor layer, the resulting components of radiation may be as described with respect to Fig. 14. In the case of other colors impinging on a phosphor layer, the forward transferred light and the back transferred light may be the same color as the impinging light. For example, if red light impinges on phosphor layer 706, the forward transferred light and the back transferred light may also be red light. The same result would obtain with green light, or any other color besides blue. The same results may obtain if a diffuser material other than phosphor is used.

[0085] Figs. 8A through 8E depict different cross-section shapes of the optic element that may be used with the embodiments of the SPE™ technique described herein. Optic element 801 illustrated in Fig. 8A is of a conical geometry having a top surface 8012. Alternative optic element 802 illustrated in Fig. 8B is of a spherical geometry having a top surface 8022. Alternative optic element 803 illustrated in Fig. 8C is of a hyperbolic geometry having a top surface 8032. Alternative optic element 804 illustrated in Fig. 8D may have conical walls and a concave top surface 8042. Alternative optic element 805 illustrated in Fig. 8E may have conical walls and a convex top surface 8052. Other geometrical shapes may include a parabolic or elliptical shape. In addition, the top of the wider surface of each optical element may be flat, or may have another geometrical shape.

[0086] Similar to the other embodiments, optic elements 801 through 805 may be made of a substantially transparent material, thereby functioning like an optical lens (similar to optic device 606 of Fig. 6).

[0087] Although not shown in Figs. 8A to 8E, a reflector (similar to reflector 702, shown in Fig. 7) may be positioned to surround each optical element 801 through 805. Furthermore, each optical element 801 through 805 may include a down-conversion material layer and a diffuser layer (similar to phosphor layer 706 and diffuser layer 705 shown in Fig. 7A). This phosphor layer and diffuser layer (not shown in Figs. 8A to 8E) may be deposited on top one of the respective top surfaces 8012, 8022, 8032, 8042, 8052 of each optical element, opposite to its respective light emitting source. Alternatively, this phosphor layer and diffuser layer (not shown in Figs. 8A to 8E) may be sandwiched within each optical element, near one of the respective top surfaces 8012, 8022, 8032, 8042, 8052 of the respective optical elements and opposite to its respective light emitting source. In other embodiments, as discussed with respect to Fig. 7A, the positions of the phosphor layer 706 and the diffuser layer (not shown in Figs. 8A to 8E) be switched. That is, phosphor layer 706 may be located on top of a respective one of the optic devices 801, 802, 803, 804, 805 and a diffuser layer (not shown in Figs. 8A to 8E) may be located on top of the phosphor layer 706. In yet another embodiment, phosphor layer 706 may be used without a diffuser

layer. In still another embodiment, a diffuser layer (not shown in Figs. 8A to 8E) may be used without phosphor layer 706.

[0088] Figs. 8F and 8G illustrate the embodiments of invention using the SPE™ technique includes respective radiation sources, respective reflectors, and an optic device that may exhibit one of the cross-section shapes 801 through 805 illustrated in Figs. 8A to 8E. In Fig. 8F, a reflector 806 and a secondary optic device 810 are both revolved objects with a common central axis (not shown). In Fig. 8G, a reflector 812 and an optic device 814 are both extruded along their respective long axis. The sectional view of reflectors 806 and 812 may have a cross-section shape of a parabola, or other geometrical shapes, such as a cone, a sphere, a hyperbola, an ellipse, a pyramid, or may be box-shaped, for example.

[0089] Referring next to Figs. 9A and 9B, there is shown a two dimensional linear array of lenses, generally designated as 900. As shown in Fig. 9A, an array of NxM high efficiency light source devices are arranged on top of a lightpipe 912. Although lightpipe 912 is illustrated in Fig. 9A as having a rectangular shape, it will be understood that it may have a shape other than rectangular. Three of the exemplary light source devices are designated as 910, 920 and 930. The remaining light source devices in the NxM array may be identical to any one of the light source devices 910, 920, or 930. In alternative embodiments, lightpipe 912 may have a circular shape or another shape. Also in alternative embodiments, the array of lenses may have a radial placement or may be placed in other patterns.

[0090] As best shown in Fig. 9B, each of light source devices 910, 920, 930 may include radiation emitter 902, lens 904 such as optic device 606 and a phosphor layer (not shown), which may be similar to phosphor layer 604 of Fig. 6. Also included may be a reflector 906, which may redirect transmitted and reflected light from radiation emitter 902 towards lightpipe 912.

[0091] Lightpipe 912, as shown, may include side 914 abutting light source devices 910, 920, and 930, and another opposing side 916 further away from the light source devices. On top of opposing side 916, there may be a microlens layer 918. The microlens layer may be bonded to the deposited phosphor layer.

[0092] As best shown in Fig. 9C, one or more of the exemplary light source devices 910, 920 and 930 may be similar to device 710 of Fig. 7A, including multiple colored light emitting sources, a lens such as optic device 704, a down conversion material layer such as layer 706, and a diffuser layer such as layer 705. For example, in this alternative embodiment, light source device 910 may include multiple colored light emitting sources 902, lens 904 such as optic device 704, a down conversion material layer (not shown), which may be similar to down conversion material layer 706 of Fig. 7A, and a diffuser layer (not shown), which may be similar to diffuser layer 705 of Fig. 7A. Also included may be a reflector 906, which may be similar to the reflector 702 of Fig. 7A. Each of the other

light source devices may also have multiple colored light emitting sources, a lens such as the optic device disclosed with respect to Fig.7A, a down conversion material layer and a diffuser layer similar to the elements contained in light source device 910. In yet another embodiment, optic device 904 may not have a down conversion material layer deposited on it.

[0093] Lightpipe 912, as shown in Fig.9C, includes side 914 abutting exemplary light source devices 910, 920 and 930, and another opposing side 916 further away from the exemplary light source devices. On top of opposing side 916, there may be deposited microlens layer 940.

[0094] Figs. 10A and 10B illustrate another exemplary embodiment of a high efficiency light source, generally designated as 1040, in which individual light source devices may be spaced around the edges of a lightpipe 1042. As shown in Fig.10A, several light devices, such as exemplary light source devices 1046, 1048, 1050, and 1052, etc. may be placed around the edges of lightpipe 1042.

[0095] A cross-section of exemplary high-efficient light source 1040 is shown in Fig.10B. As shown in Fig.10B, exemplary light source device 1046 may be configured to direct light into lightpipe 1042. Lightpipe 1042 may include a first side 1062 of light pipe 1042 and a second side 1064. A microlens layer 1066 may be placed adjacent first side 1062 of light pipe 1042 and another microlens layer 1068 may be placed adjacent second side 1064 of lightpipe 1042. Although lightpipe 1042 is illustrated as having a polygonal shape, it may also have a circular shape or other shape.

[0096] In one embodiment of the embodiment illustrated in Figs. 10A and 10B, each of the exemplary light source devices 1046, 1048, 1050 and 1052 may be similar to device 700 of Fig.7, including a short wavelength radiation emitter, a lens such as an optic device described herein, and a down conversion material layer. For example, exemplary light source device 1046 may be mounted onto edge 1060 of lightpipe 1042. Exemplary light source device 1046 may include short wavelength radiation emitter 1054, lens 1056 such as optic device 606, and a down conversion material layer (not shown), which may be similar to down conversion material layer 604 of Fig.6 or similar to down conversion material layer 706 of Fig.7A. Also included may be reflector 1058, which may redirect the back transferred radiation and forward transferred radiation from lens 1056 towards the edge 1060 of lightpipe 1042, and into lightpipe 1042. The reflector 1058 may be similar to reflector 702 of Fig.7. Additional light source devices may be placed along edge 1060 and along edge 1070. Even more light source devices may be placed along the other two edges of lightpipe 1042 that are not shown in Figs. 10A and 10B. All of the light source devices, other than light source device 1046, may also have a similar short wavelength radiation emitter, a lens, and a down conversion material layer similar to the elements contained in light source device 1046. It will be

understood that even though Fig.10A shows five light source devices along each of edges 1060 and 1070, fewer or more light source devices may be used along each of edges 1060 and 1070 and along the edges that are not shown in Fig.10A.

[0097] In another alternative embodiment, one or more of the exemplary light source devices 1046, 1048, 1050 and 1052 may be similar to device 710 of Fig.7A, including multiple colored light emitting sources, a lens such as an optic device, a down conversion material layer, and a diffuser layer. In this alternative embodiment, exemplary light source device 1046 may include multiple colored light emitting source 1054, lens 1056 such as optic device 704, a down conversion material layer (not shown), which may be similar to down conversion material layer 706 of Fig.7A, and a diffuser layer (not shown), which may be similar to diffuser layer 705 of Fig.7A. Each of the exemplary light source devices shown in Fig.10A may also have a reflector such as exemplary reflector 1058, which may be similar to the reflector 702 of Fig.7A. The reflector may re-direct light from the multiple colored light emitting sources and the back transferred light from respective down-conversion material or diffuser layer toward the edge 1060 of lightpipe 1042, and into lightpipe 1042. Each of the other light source devices may also have multiple colored light emitting sources, a lens, a down conversion material layer and a diffuser layer similar to the elements contained in light source device 1046 that may transmit their respective light into lightpipe 1042 through respective edges of lightpipe 1042. In another embodiment, optic device 1056 may not have the diffuser layer. In yet another embodiment, optic device 1056 may not have a down conversion material layer deposited on it.

[0098] On top of sides 1062 and 1064 of Lightpipe 1042, as shown in Fig.10B, there may be deposited microlens layer 1066 and 1068.

[0099] Fig.11 illustrates still another exemplary embodiment of the invention. As shown, device 1110 includes a short wavelength radiation source 1100, a lens 1102 which may be any of the optic devices described herein, and a phosphor layer 1104. The phosphor layer may be deposited on top of lens 1102, so that the phosphor layer is away from the short wavelength radiation source 1100, in a manner that is similar to that shown in Figs. 6, 7, 7A, for example. The light source/lens/phosphor configuration may be at least partially surrounded by a reflector 1106 having a high-reflectance. In an exemplary embodiment the measured reflectance of reflector 1106 may be in the range of 90% to 97%. In addition, a high efficiency microlens diffuser 1108 may be placed across the top of reflector 1106. In an exemplary embodiment, the microlens diffuser may exhibit greater than 95% efficiency. The reflectance of other reflectors described in this application may be the same as the reflectance of reflector 1106. The efficiency of other diffusers described in this application may be the same as the efficiency of diffuser 1108.

[0100] Fig.11A illustrates another embodiment of the invention. Fig.11A shows a device 1120 which may include multiple colored radiation emitting sources 1122, an optic device 1124, and a down conversion material layer 1126. The optic device 1124 may be mounted adjacent the multiple colored radiation emitting sources 1122. The down conversion material layer 1126 may be mounted or deposited on one portion or on one end 1129 of the optic device 1124 so that the down conversion material layer 1126 is away from the multiple colored radiation emitting devices 1122. Although Fig.11A illustrates three multiple colored radiation emitting sources 1122, it will be understood that more or fewer multiple colored radiation emitting sources 1122 may be used for the reasons explained with respect to other embodiments illustrated in this application. The package comprising the array of multiple colored radiation emitting sources 1122, the optic device 1124, and the down conversion material layer 1126 may be at least partially surrounded by a reflector 1128 having a high reflectance. In an exemplary embodiment of this alternative embodiment, the measured reflectance of reflector 1128 may be in the range of 90% to 97%. A high efficiency microlens diffuser 1130 may be placed across end 1132 of reflector 1128. End 1132 may be open if a diffuser is not placed across it. In an exemplary embodiment, microlens diffuser 1130 may exhibit greater than 95% efficiency. In an alternative embodiment of the embodiment illustrated in Fig.11A, a diffuser may be used in place of down conversion material layer 1126 and diffuser layer 1130 may be eliminated. In another embodiment, the side walls of optic device 1124 may be painted white in order to improve color mixing.

[0101] Fig.12 illustrates yet another exemplary embodiment of the invention. As shown, device 1210 includes short wavelength radiation source 1200 facing phosphor layer 1202 and reflector 1206. A substantially transparent medium 1204 may fill the space between short wavelength radiation source 1200 and phosphor layer 1202. In an exemplary embodiment, phosphor layer 1202 may be in the shape of a parabola, or other curved shape, similar to one of the geometric shapes previously enumerated. Reflector 1206 may be spaced away from the phosphor layer 1202 and the radiation source 1200. A substantially transparent medium 1208 may be used to fill the space between the phosphor layer 1202 and the reflector 1206. As shown, phosphor layer 1202 is disposed between the light source 1200 and reflector 1206.

[0102] Fig.12A illustrates still another exemplary embodiment of the invention. As shown, device 1220 in Fig.12A has a radiation source comprising multiple colored light emitting sources 1222 facing down conversion material layer such as a phosphor layer 1202 and a reflector 1206. Phosphor layer 1202 is disposed away from light emitting sources 1222. A substantially transparent medium 1204 may be positioned between multiple colored light emitting sources 1222 and down conversion material layer 1202. In an exemplary embodiment, the down

conversion material layer 1202 may be in the shape of a parabola or other curved shape. Reflector 1206 may be spaced away from the down conversion material layer 1202 and the multi-colored LED array 1222. A substantially transparent medium 1208 may be present between the down conversion material layer 1202 and the reflector 1206. In this embodiment, the down conversion material layer 1202 is disposed between the light emitting sources 1222 and the reflector 1206. In an alternative embodiment, a diffuser layer may be placed across an end 1224 of reflector 1206. End 1224 may be open if a diffuser layer is not placed across it. In another alternative embodiment, a diffuser layer may be used instead of a down conversion material layer 1202. If a diffuser layer is used instead of a down conversion material layer, a diffuser layer may not be placed across end 1224.

[0103] While it is well known that the phosphor used in white light-emitting diodes (LEDs) backscatters more than half the light emitted, no one to date has shown that this light may be recovered as photons to increase the overall efficacy of a white light source. The inventors have experimentally verified a scattered photon extraction (SPE™) method provided by the various embodiments of the invention, that significantly increases the overall efficacy of a white light source. At low currents, the SPE™ package showed over 80 lm/W white light with chromaticity values very close to the blackbody locus.

[0104] Of the different methods available for creating white light, the phosphor-converted emission method is the most common. A first phosphor-converted white LED uses cerium doped yttrium aluminum garnet (YAG:Ce) phosphor in combination with a gallium nitride (GaN) based blue LED. In a typical white LED package, the phosphor is embedded inside an epoxy resin that surrounds the LED die. Some portion of the short-wavelength radiation emitted by the GaN LED is down-converted by the phosphor, and the combined light is perceived as white by the human eye. Although these products proved the white LED concept and have been used in certain niche illumination applications, they are not suited for general lighting applications because of their low overall light output and low efficacy.

[0105] To achieve higher luminous efficacy with white LEDs, improvements are needed at several stages: internal quantum efficiency, extraction efficiency, and phosphor-conversion efficiency. Some researchers have taken on the challenge of researching the materials and growth aspects of the semiconductor to improve internal quantum efficiency. Others are exploring shaped chips, photonic crystals, micron-scale LEDs, and other novel methods to improve light extraction efficiency. Still others are investigating new phosphors that have greater down-conversion efficiencies and better optical properties.

[0106] Although past literature acknowledges that a significant portion of the light is backscattered by the phosphor and lost within the LED due to absorption, to the best of the inventors' knowledge no one to date has attempted to improve performance by extracting these

backscattered photons, by way of the SPE™ method, provided by the embodiments of the present invention, which significantly increases the overall light output and luminous efficacy of a phosphor-converted white LED by recovering the scattered photons.

[0107] To better understand the interaction between primary short-wavelength light and phosphor and to quantify the amount of forward and backward scattered light, several circular glass plates, 5 cm in diameter, were coated by the inventors with different densities of YAG:Ce phosphor ranging from 2 mg/cm² to 8 mg/cm². These phosphor plates were placed between two side-by-side integrating spheres with the phosphor coating facing the right sphere. The phosphor material was excited by radiation from a 5 mm blue LED placed inside the right sphere 2.5 cm away from the glass plate. A spectrometer measured the light output from each sphere through the measurement ports. Light output measured from the left and right spheres indicated the amount of light transmitted through and reflected off the phosphor layer, respectively. The spectrometer data was analyzed to determine the amount of flux in the blue and yellow regions, corresponding to the radiant energy emitted by the LED and the converted energy from the YAG:Ce phosphor.

[0108] Experimental results showed that the spectral power distributions for the transmitted and reflected radiations are different, especially the amount of blue-to-yellow ratio. The amount of transmitted and reflected radiations depends on the phosphor density, with lower densities resulting in higher percentages of transmitted radiation. Typically, the phosphor density may be controlled such that the transmitted blue and yellow light are in the correct proportion to produce white light of a suitable chromaticity, which typically places it on or close to the blackbody locus. From the gathered data, it was estimated that about 40% of the light is transmitted when creating a balanced white light, and the remaining 60% is reflected. Yamada et al. found similar results, as reported in K. Yamada, Y. Imai, K. Ishii, J. Light & Vis. Env. 27(2), 70 (2003). In a conventional white LED, a significant portion of this reflected light is absorbed by the components surrounding the die, one of the reasons for its low luminous efficacy.

[0109] A method by which most of the reflected light may be recovered is illustrated in Fig. 13, which shows schematically an LED package with SPE™ implemented. Unlike a typical conventional white LED package, where the phosphor is spread around the die, in the SPE™ package of the invention the phosphor layer is moved away from the die, leaving a transparent medium between the die and the phosphor. An efficient geometrical shape for the package may be determined via ray tracing analysis. The geometry of the package plays an important role, and the geometry shown in Fig. 13 efficiently transfers the light exiting the GaN die to the phosphor layer and allows most of the backscattered light from the phosphor layer to escape the optic. Compared with

the typical conventional package, more photons are recovered with this SPE™ package. Here again the phosphor density determines the chromaticity of the final white light.

[0110] It is worth noting that the SPE™ package requires a different phosphor density to create white light with chromaticity coordinates similar to the conventional white LED package. This difference is a result of the SPE™ package mixing transmitted and back-reflected light with dissimilar spectra, whereas the conventional package uses predominantly the transmitted light.

[0111] To verify that the SPE™ package shown in Fig. 13 provides higher light output and luminous efficacy, an experiment was conducted with twelve conventional high-flux LEDs, six 3 W blue and six 3 W white, obtained from the same manufacturer. A commercial optic that fit the profile requirements of the SPE™ package was found, and several were acquired for experimentation with the LEDs. Although this optical element did not have the desired geometry shown in Fig. 13 to extract most of the backscattered light, it was sufficient to verify the hypothesis. The top flat portion of the experiment's secondary optic was coated with a predetermined amount of YAG:Ce phosphor. The required phosphor density was determined in a separate experiment by systematically varying the amount of phosphor density, analyzing the resulting chromaticity, and selecting the density that produced a chromaticity close to that of the commercial white LED used in the experiment. To compare the performances of the two packaging concepts, the white LEDs were fitted with uncoated secondary optics. The light output and the spectrum of the commercial white LEDs were measured in an integrating sphere, and the current and the voltage required to power the LEDs were also measured. The same measurements were repeated for the SPE™ packages, which included blue LEDs fitted with phosphor-coated secondary optics, as shown in Fig. 13.

[0112] The average luminous flux and the corresponding average efficacy for the SPE™ LED packages were found to be 90.7 lm and 36.3 lm/W, respectively. The average luminous flux and the corresponding average efficacy for the typical white LED packages were 56.5 lm and 22.6 lm/W, respectively. Therefore, the SPE™ LED packages on average had 61% more light output and 61% higher luminous efficacy. The variation of luminous flux and corresponding efficacy between similar LEDs was small, with a standard deviation of less than 4%. The SPE™ packages consistently had higher lumen output and higher efficacy compared with the typical conventional white LED packages.

[0113] The impact of current on light output and efficacy was also measured on two LED packages, one typical white LED and one SPE™ package. These two LEDs were subjected to the same light output measurement procedure, but their input current was decreased from 700 mA to 50 mA in several steps, and the corresponding photometric and electrical data were gathered. At very low currents, the SPE™ package exceeded 80 lm/W,

compared to 54 lm/W for the conventional package.

[0114] With the SPE™ package, the backscattered photons are extracted before they are absorbed by the components within the LED. It is essential that the phosphor layer be placed farther away from the die, and the backscattered photons be extracted before they undergo multiple reflections within the package. Moving the phosphor away from the die has an additional benefit: the life of the white LED is also improved, as demonstrated in an earlier paper (Narendran, N., Y. Gu, J.P. Freyssinier, H. Yu, and L. Deng. 2004. Solid-state lighting: Failure analysis of white LEDs. *Journal of Crystal Growth* 268 (3-4): 449-456).

[0115] An alternate method of the present invention to recover a portion of the back transferred radiation is to coat the sides of the secondary optics with a reflective material, as shown in Figs. 5A and 5B. Although the efficacy may improve compared to a conventional white LED package, the gain is not as much, because the back transferred radiation bounces back and forth between the phosphor layer and the reflectors, and a good portion of this radiation is absorbed and lost as heat. A drawback of this method is by increasing the path length of the short-wavelength radiation traveling through the surrounding epoxy material, the epoxy degrades faster and thus shortens the useful life of the white LED.

[0116] It will be understood that the geometry of the SPE™ package shown in Fig. 13 is not limited to this specific shape. Alternate shapes may be used to recover the back transferred radiation more efficiently, while addressing other design concerns, such as color and life. As one example, in the configuration of Fig. 13, the inventors discovered that a preferred size for the top surface diameter is about 20mm and a preferred size for the height is about 11mm.

[0117] In summary, the present invention recovers the back transferred radiation from the down conversion material layer or the diffuser layer. In addition, the overall light output and the corresponding luminous efficacy of the LED system may be increased significantly compared to its conventional package. At the same time, the optic device may mix multiple spectra to create white light and other shades of colors while with uniform illumination and color. Applications of embodiments of the invention include general illumination and backlighting.

[0118] Although the invention has been described with reference to exemplary embodiments, it is not limited thereto. Rather, the appended claims should be construed to include other variants and embodiments of the invention which may be made by those skilled in the art without departing from the scope of the present invention.

[0119] In one embodiment of the invention, the plurality of light sources comprises at least one of one of light emitting diodes (LEDs), laser diodes (LDS), and resonant cavity light emitting diodes (RCLEDs).

[0120] In one embodiment of the invention, the plurality of light emitting sources are disposed at a predetermined distance from the diffuser material.

[0121] In one embodiment of the invention, the plurality of light emitting sources is disposed adjacent a first portion of the optic device.

[0122] In one embodiment of the invention, the diffuser material is disposed over one of a portion of a second end of the optic device or over substantially all of the second end of the optic device.

[0123] In one embodiment of the invention, the down conversion material includes at least one material for absorbing radiation of a first wavelength in a spectral region and emitting radiation of a second wavelength longer than the first wavelength in the spectral region.

[0124] In one embodiment of the invention, the diffuser material comprises at least one layer of down conversion material adjacent the diffuser.

[0125] In one embodiment of the invention, the diffuser material for receiving the multicolored radiation comprises a plurality of down conversion materials for absorbing radiation of a first wavelength in a spectral region and emitting radiation of at least a second wavelength in the spectral region longer than the first wavelength.

[0126] In one embodiment of the invention, a shape of the reflector is one of a cone, sphere, hyperbola, parabola, ellipse, pyramid, and box.

[0127] In one embodiment of the invention, the collecting device is disposed adjacent at least two sides of the optic device.

[0128] In one embodiment of the invention, it further comprises a heat dissipation device coupled to the radiation source.

[0129] In another embodiment of the invention, the light emitting apparatus comprises: a radiation source for emitting multi-colored radiation; an optic device configured to receive radiation emitted from the radiation source; a diffuser material disposed on a portion of the optic device receiving at least a portion of the multi-colored radiation received by the optic device and converting the portion of the multi-colored radiation into forward transferred light and back transferred light, wherein the optic device is configured to extract a portion of the back transferred light.

[0130] In one embodiment of the invention, the radiation source comprises a plurality of light emitting sources, each of the light emitting sources exhibiting a spectrum different than a spectrum of at least one other of the other light emitting sources.

[0131] It follows a list of examples

1. A light emitting apparatus comprising : a radiation source for emitting multi-colored radiation; a diffuser material for receiving at least a portion of the multi-colored radiation emitted by the radiation source and converting the multi-colored radiation into forward transferred radiation and back transferred radiation; and an optic device coupled to the diffuser material adapted to receive the back transferred radiation and extract at least a portion of the back transferred radiation from the optic device.

2. The light emitting apparatus of example 1, wherein the radiation source comprises a plurality of light emitting sources, each of the light emitting sources exhibiting a spectrum different than a spectrum of at least one of the other light emitting sources.

3. The light emitting apparatus of example 2, wherein the plurality of light sources comprises at least one of one of light emitting diodes (LEDs), laser diodes (LDs), and resonant cavity light emitting diodes (RCLEDs).

4. The light emitting apparatus of example 2, wherein a first plurality of light emitting sources are disposed adjacent a first side of the diffuser material and a second plurality of light emitting sources are disposed adjacent a second side of the diffuser material.

5. The light emitting apparatus of example 2, wherein the plurality of light emitting sources are disposed at a predetermined distance from the diffuser material.

6. The light emitting device of example 2, wherein the plurality of light emitting sources is disposed adjacent a first portion of the optic device.

7. The light emitting device of example 6, wherein the diffuser material is disposed adjacent a second portion of the optic device.

8. The light emitting device of example 7, wherein the diffuser material is disposed over one of a portion of a second end of the optic device or over substantially all of the second end of the optic device.

9. The light emitting apparatus of example 2, further comprising a light pipe, wherein the plurality of light emitting sources are disposed about at least a portion of a circumference of the light pipe for directing the light into the light pipe.

10. The light emitting apparatus of example 9, further comprising a micro lens layer disposed on a side of the light pipe.

11. The light emitting apparatus of example 1, wherein the diffuser material for receiving the multi-colored radiation is at least one of a diffuser, a down conversion material, and a microlens.

12. The light emitting apparatus of example 11, wherein the down conversion material includes at least one material for absorbing radiation of a first wavelength in a spectral region and emitting radiation of a second wavelength longer than the first wavelength in the spectral region.

13. The light emitting apparatus of example 11, wherein the down conversion material comprises one of a layer having substantially uniformly dispersed material, a layer having a plurality of materials each of the plurality of materials exhibiting a respective density, or material dispersed within the optic device.

14. The light emitting apparatus of example 11, wherein the diffuser material comprises at least one layer of down conversion material adjacent the diffuser.

15. The light emitting apparatus of example 11, wherein the diffuser material comprises at least one layer of down conversion material positioned away from the diffuser.

16. The light emitting apparatus of example 1, wherein the diffuser material for receiving the multi-colored radiation comprises a plurality of down conversion materials for absorbing radiation of a first wavelength in a spectral region and emitting radiation of at least a second wavelength in the spectral region longer than the first wavelength.

17. The light emitting apparatus of example 1, wherein the diffuser material for receiving the multi-colored radiation comprises at least one of i) a plurality of diffuser layers and ii) a plurality of down conversion material layers.

18. The light emitting apparatus of example 1, further comprising a collecting device for collecting at least a portion of the back transferred radiation leaving the optic device.

19. The light emitting apparatus of example 18, wherein the collecting device includes a reflector disposed around at least a portion of the optic device.

20. The light emitting apparatus of example 19, wherein a shape of the reflector is one of a cone, sphere, hyperbola, parabola, ellipse, pyramid, and box.

21. The light emitting apparatus of example 18, wherein the optic device is disposed one of on the collecting device or at a distance away from the collecting device.

22. The light emitting apparatus of example 21, wherein the collecting device is disposed adjacent at least two sides of the optic device.

23. The light emitting apparatus of example 18, wherein the light source is disposed between the collecting device and the diffuser material.

24. The light emitting apparatus of example 1, wherein the diffuser material is dispersed within the optic device.

25. The light emitting apparatus of example 1, further comprising a heat dissipation device coupled to the radiation source.

26. A light emitting apparatus comprising: a radiation source for emitting multi-colored radiation; an optic device configured to receive radiation emitted from the radiation source; a diffuser material disposed on a portion of the optic device receiving at least a portion of the multi-colored radiation received by the optic device and converting the portion of the multi-colored radiation into forward transferred light and back transferred light, wherein the optic device is configured to extract a portion of the back transferred light.

27. The light emitting apparatus of example 26, wherein the radiation source comprises a plurality of light emitting sources, each of the light emitting sources exhibiting a spectrum different than a spec-

trum of at least one other of the other light emitting sources.

Claims

1. A light emitting apparatus comprising:

a substrate;
a plurality of radiation emitting source (24, 602, 701, 902, 1054, 1122, 1222) disposed on the substrate;
a down conversion material layer (12, 604, 706, 1104, 1126, 1202) disposed on the plurality of radiation emitting source for receiving at least a portion of the radiation emitted by the plurality of radiation emitting source (24, 602, 701, 902, 1054, 1122, 1222) and converting the radiation into forward transferred light radiation, or transmitted light radiation, and back transferred light radiation, or reflected light radiation; and
an optic device (10, 606, 704, 904, 1056, 1124, 1204) disposed on the plurality of radiation emitting source and coupled to the down conversion material layer (12, 604, 706, 1104, 1126, 1202); wherein the light emitting apparatus is **characterized in that** the down conversion material layer (12, 604, 706, 1104, 1126, 1202) comprises a plurality of segments, the plurality of segments has different down conversion material densities from each other.

2. The light emitting apparatus of claim 1, wherein the optic device covers the plurality of radiation emitting source.

3. The light emitting apparatus of claim 1, wherein the optic device disposed between the plurality of radiation emitting source and the down conversion material layer.

4. The light emitting apparatus of claim 1, wherein the down conversion material layer comprises a plurality of down conversion materials.

5. The light emitting apparatus of claim 1, further comprising a light pipe (912, 1042) distant from the plurality of radiation emitting source.

6. The light emitting apparatus of claim 1, wherein the down conversion material layer (706) has an upper surface which is flat and parallel with the substrate (703).

7. The light emitting apparatus of claim 1, further comprising a diffuser layer (20, 22, 705, 1108, 1130, 1202) disposed on the plurality of radiation emitting source and optically coupled to a down conversion

material layer.

8. The light emitting apparatus of claim 1, further comprising a collecting device (702, 812, 906, 1058, 1106, 1128, 1206) disposed on the substrate and not pervious to the radiation converted by the down conversion material layer.

9. The light emitting apparatus of claim 8, wherein the collecting device includes a reflector (702, 812, 906, 1058, 1106, 1128) disposed around at least a portion of the optic device (704, 814, 904, 1056, 1102, 1124).

10. The light emitting apparatus of claim 8, wherein the optic device (704, 814, 904, 1056, 1102, 1124) is distant from the collecting device (1058, 1106, 1128).

11. The light emitting apparatus of claim 1, wherein the down conversion material layer (706) is dispersed within the optic device (704).

12. The light emitting apparatus of claim 1, further comprising a reflector (702, 812, 906, 1058, 1106, 1128) disposed around the plurality of radiation emitting source (24, 602, 701, 902, 1054, 1122, 1222).

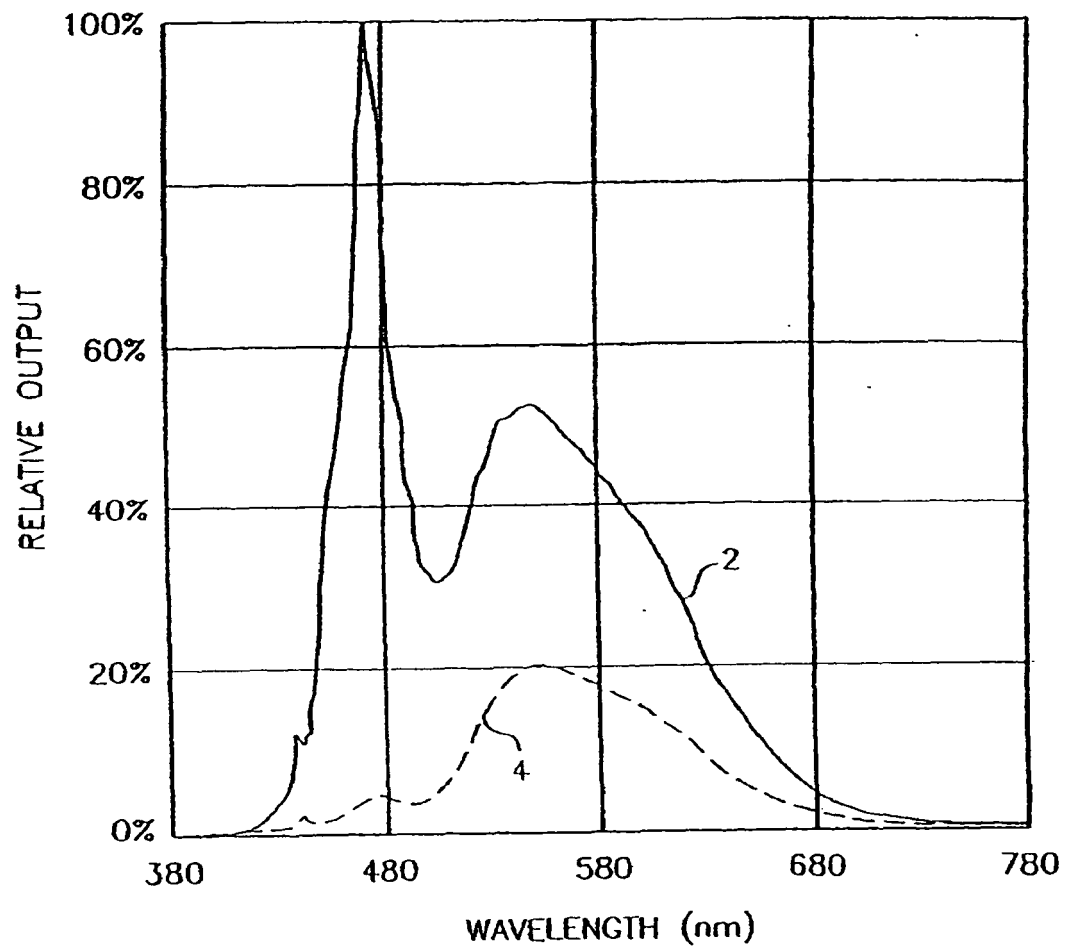


FIG. 1

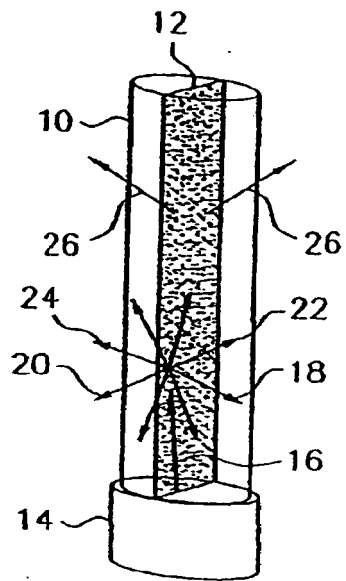


FIG. 2

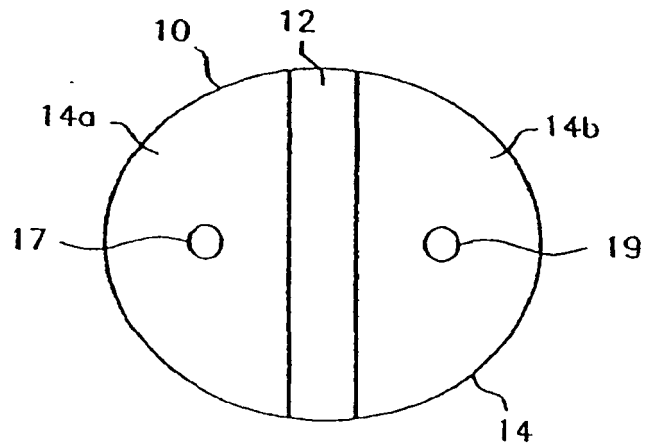


FIG. 3

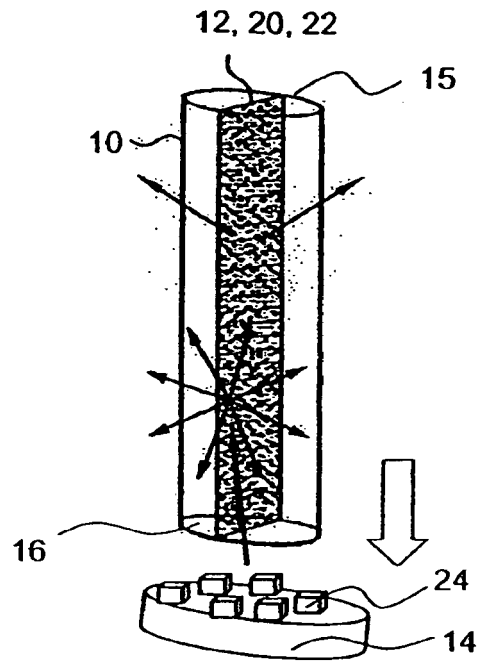


FIG. 2A

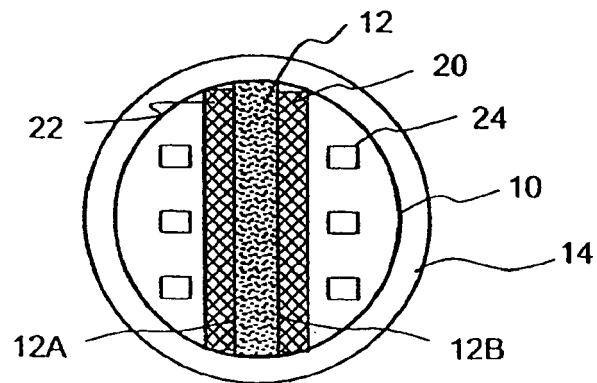


FIG. 2B

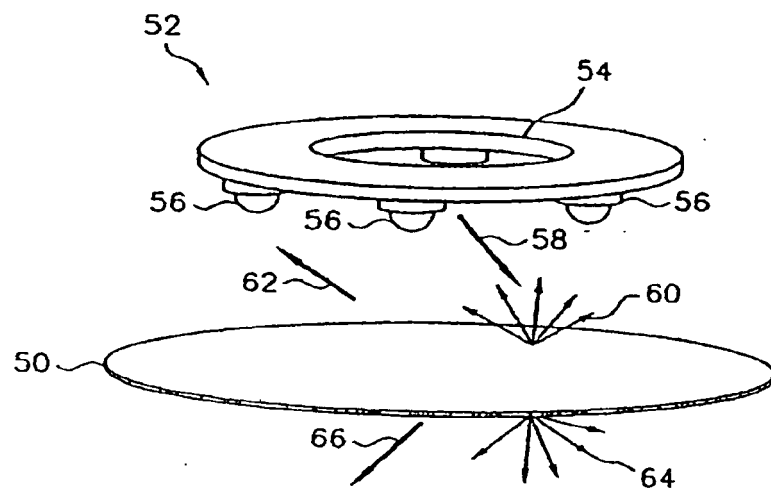


FIG. 4

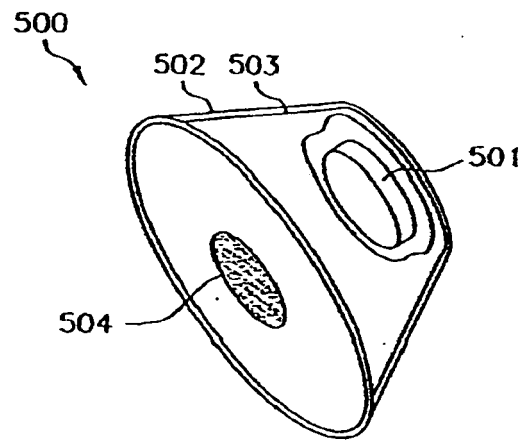


FIG. 5A

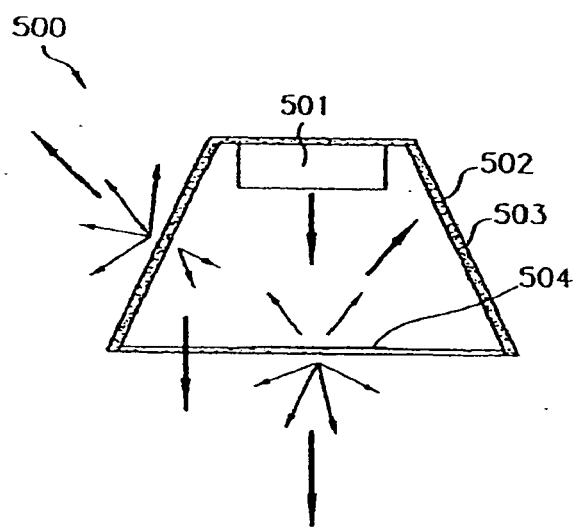


FIG. 5B

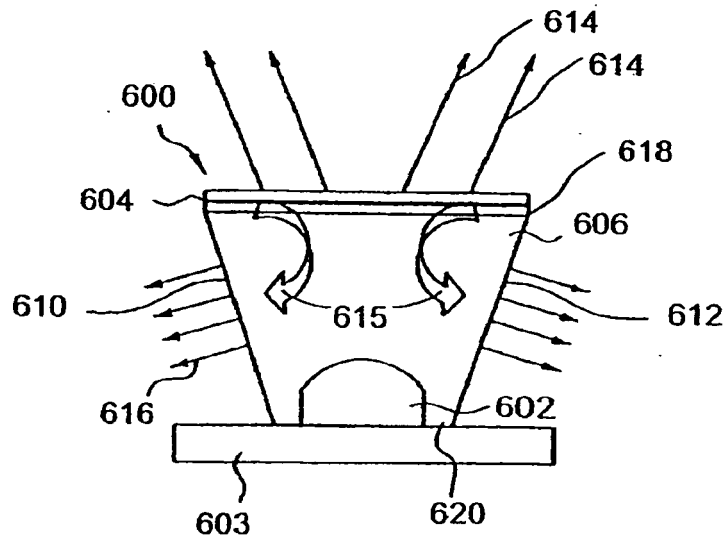


FIG. 6

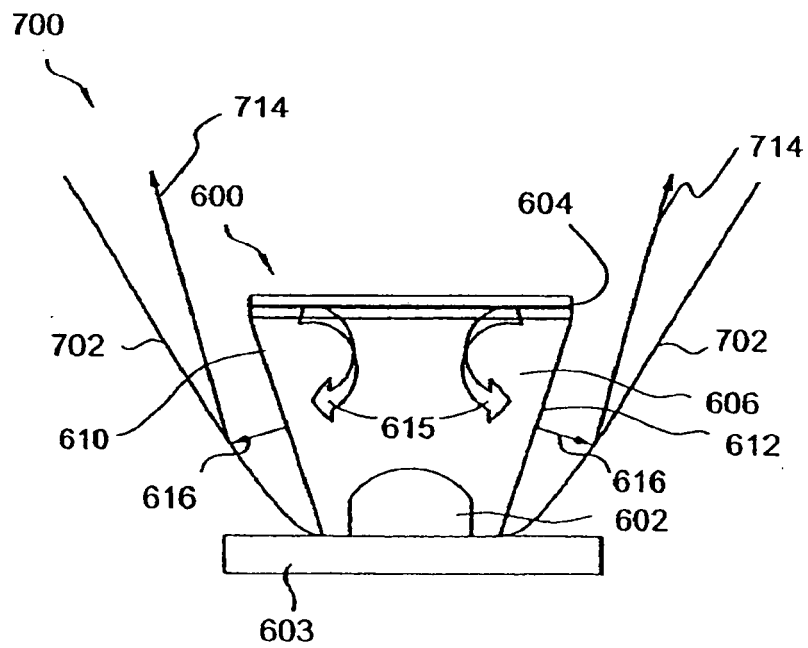


FIG. 7

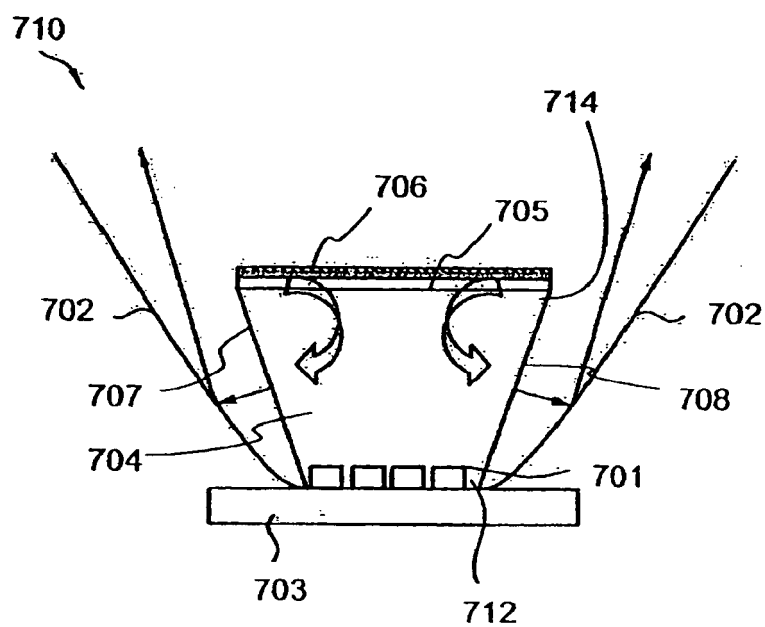


FIG. 7A

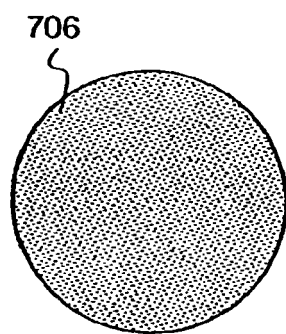


FIG. 7B

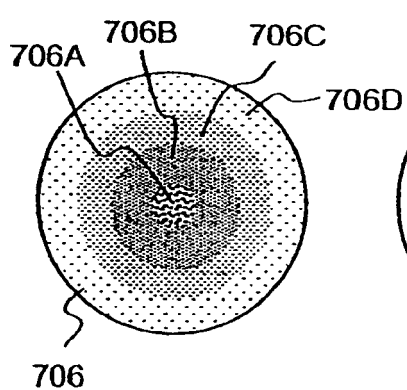


FIG. 7C

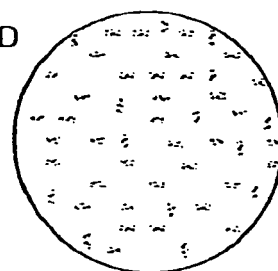


FIG. 7D

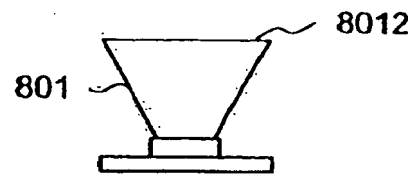


FIG. 8A

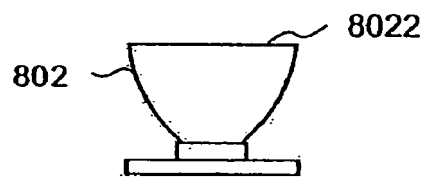


FIG. 8B

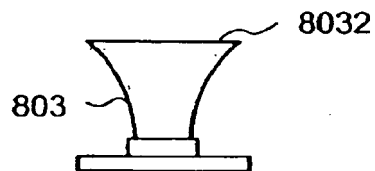


FIG. 8C

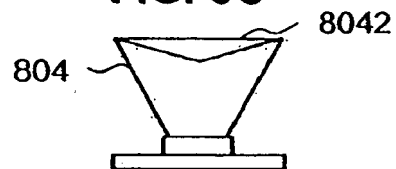


FIG. 8D

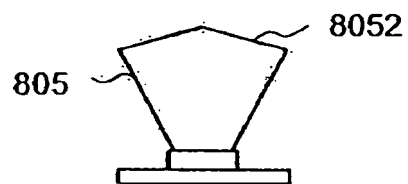


FIG. 8E

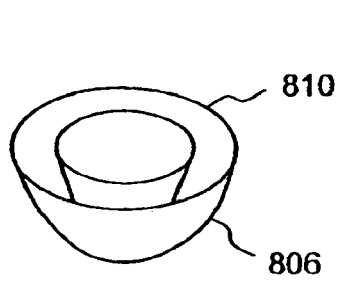


FIG. 8F

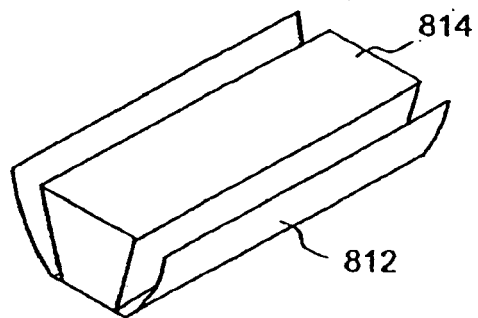


FIG. 8G

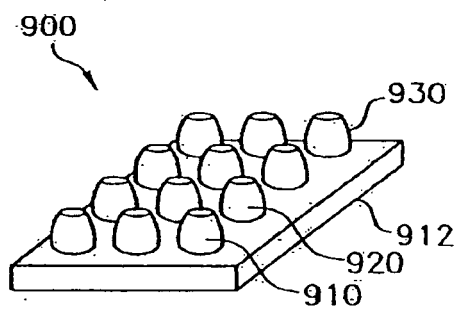


FIG. 9A

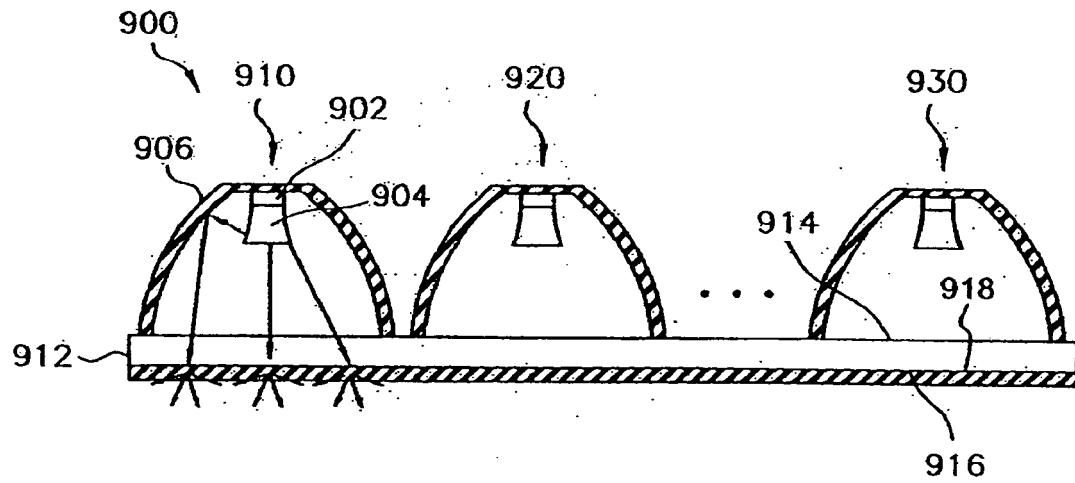


FIG. 9B

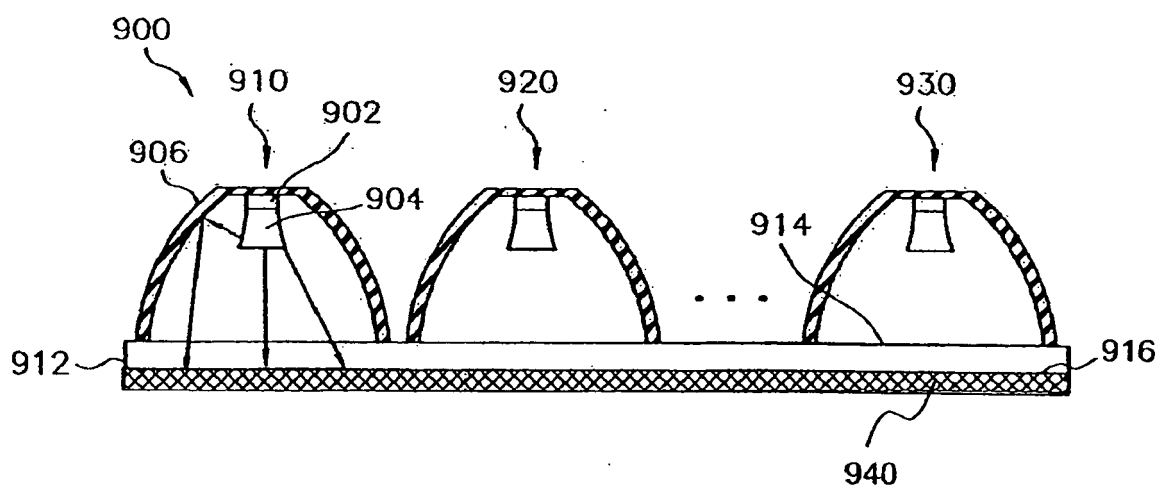


FIG. 9C

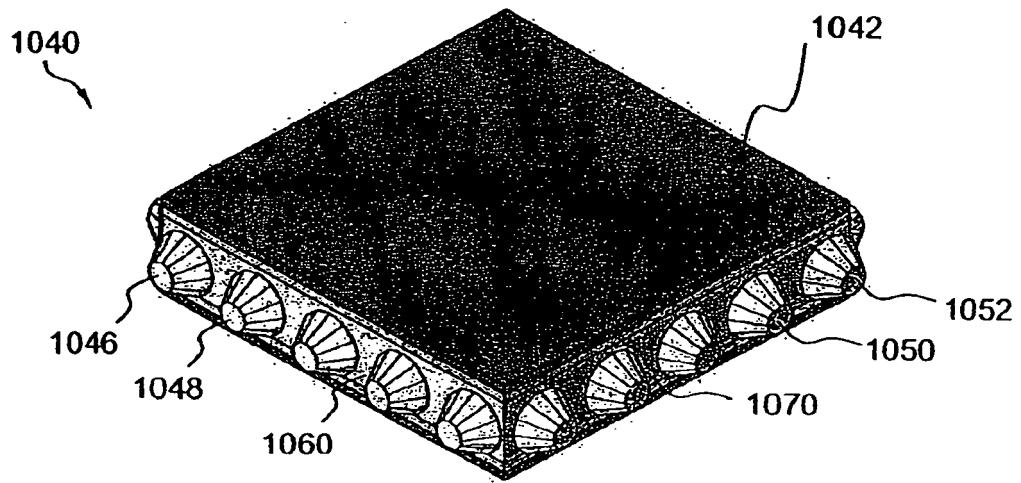


FIG. 10A

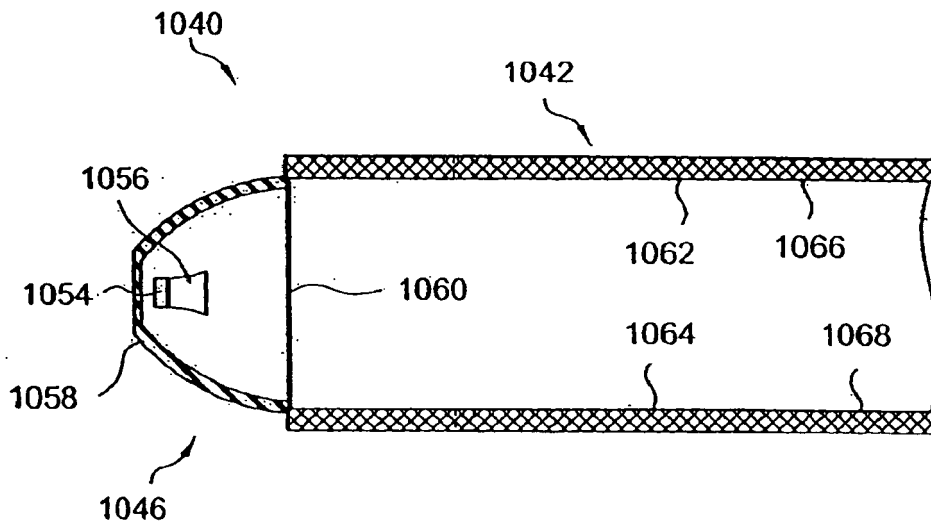


FIG. 10B

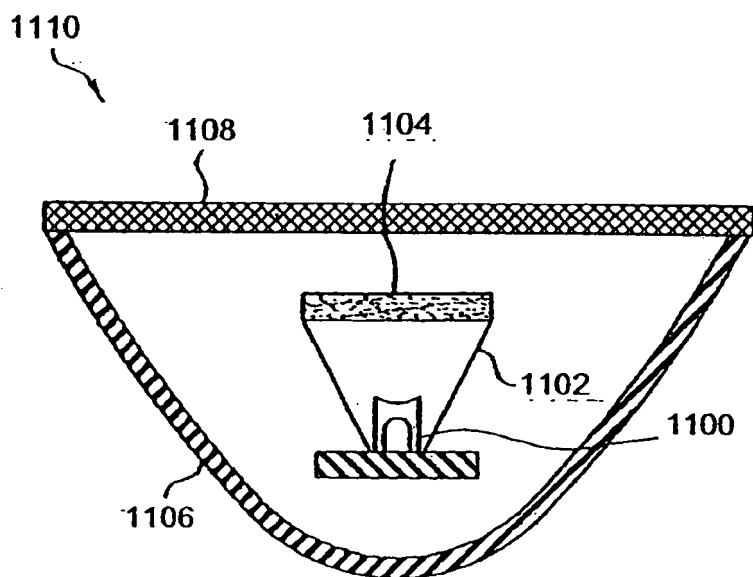


FIG. 11

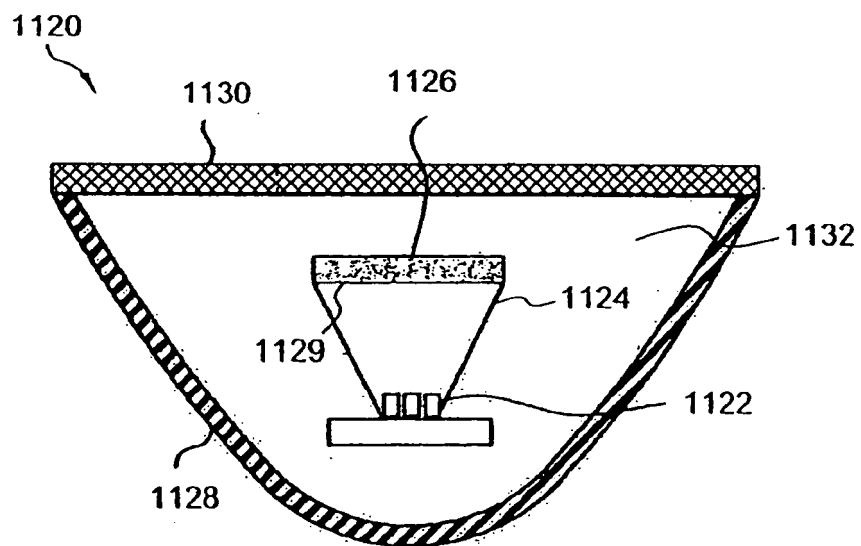


FIG. 11A

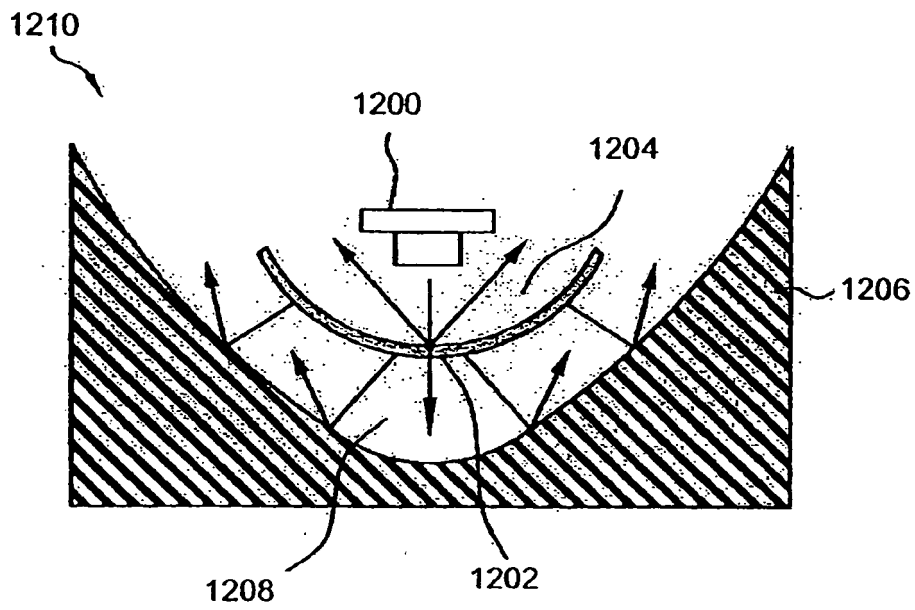


FIG. 12

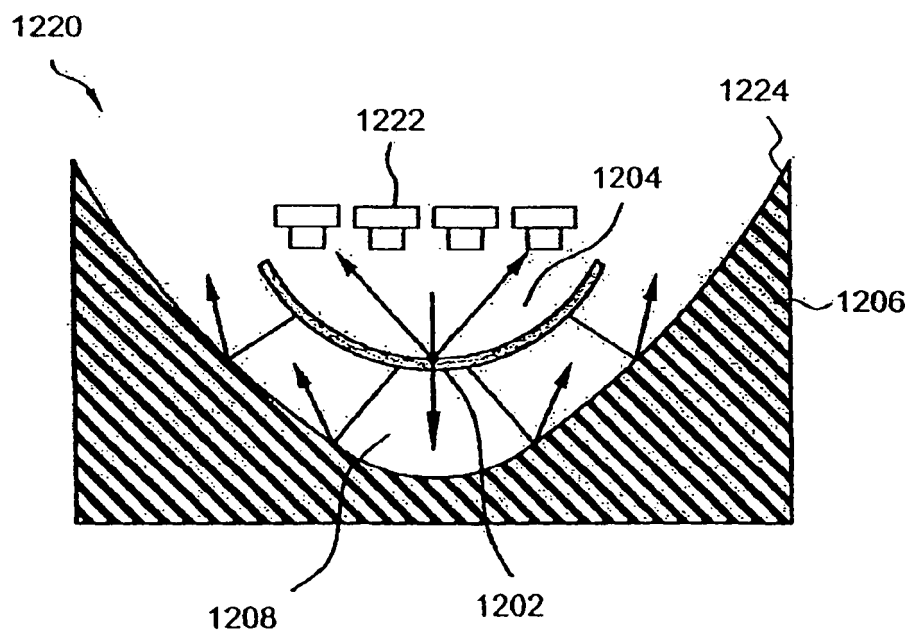


FIG. 12A

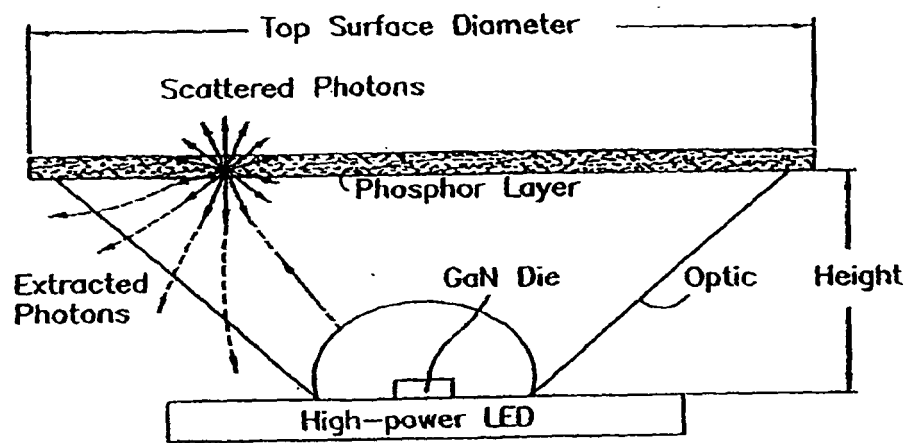


FIG. 13

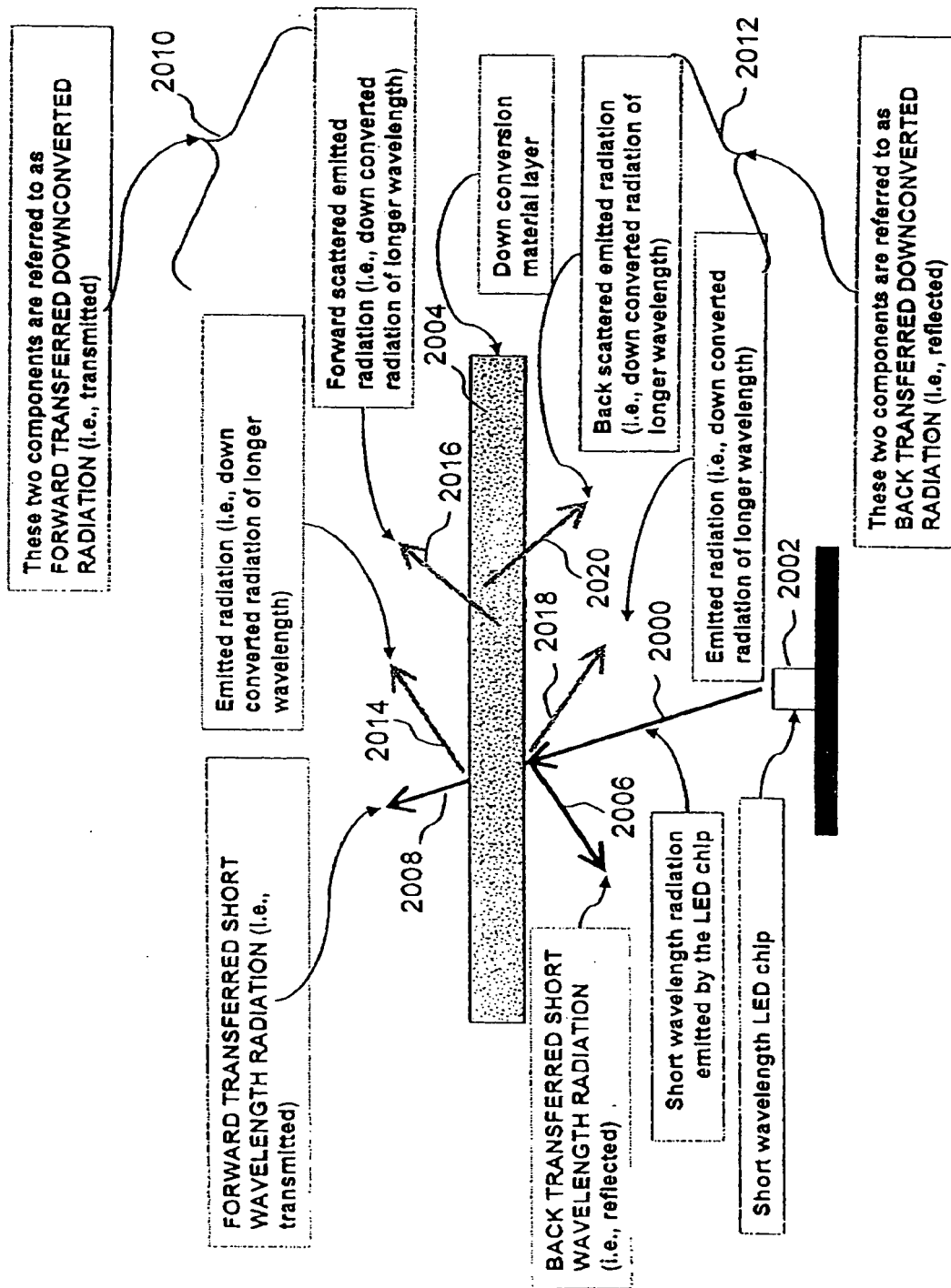


FIG. 14



EUROPEAN SEARCH REPORT

 Application Number
 EP 19 16 6740

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50

55

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y,D	WO 2005/107420 A (RENSELAER POLYTECH INST [US]; NARENDRAN NADARAJAH [US]; GU YIMIN [US]) 17 November 2005 (2005-11-17) * page 1, line 10 - page 6, line 31 * * page 9, line 13 - page 12, line 8; figures 1-3 * * page 13, line 13 - page 14, line 14; figures 6-8E * * page 15, line 28 - page 19, line 13; figure 13 *	1-12	INV. F21K9/64 H01L33/50 ADD. F21Y115/10 H01L25/075 H01L33/58
Y	JP 2004 071357 A (FUJITA SHIGEO; FUJITA SHIZUO; KAWAKAMI YOICHI; SHARP KK) 4 March 2004 (2004-03-04) * abstract * * paragraphs [0004] - [0007], [0017] - [0026]; figures 1,2 * * paragraphs [0027] - [0030]; figures 3,4 * * paragraphs [0044], [0050], [0054]; figures 6-8 *	1-12	
Y	US 2005/116635 A1 (WALSON JAMES E [US] ET AL) 2 June 2005 (2005-06-02) * paragraphs [0008], [0031], [0034] - [0037]; figure 2 * * paragraph [0040]; figures 3, 4A *	1-6,8	H01L F21K F21Y
Y	US 2004/233664 A1 (BEESON KARL W [US] ET AL) 25 November 2004 (2004-11-25) * paragraphs [0160], [0261] *	1-6,8	
----- -/--			
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 12 July 2019	Examiner Tinjod, Frank
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document	

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EUROPEAN SEARCH REPORT

Application Number
EP 19 16 6740

5

10

15

20

25

30

35

40

45

50

55

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 6 653 765 B1 (LEVINSON LIONEL M [US] ET AL) 25 November 2003 (2003-11-25) * abstract * * column 1, lines 1-16,38-60 * * column 1, line 63 - column 2, line 16 * * column 2, lines 26-32,47,48 * * column 2, line 61 - column 3, line 46; figures 1,2 * * column 3, line 55 - column 4, line 5; figure 4 * * column 4, line 25 - column 6, line 9 *	1-12	
A	WO 2006/087651 A (KONINKL PHILIPS ELECTRONICS NV [NL]; DE GRAAF JAN [NL]; VAN SPRANG HAN) 24 August 2006 (2006-08-24) * page 1, lines 13-18 * * page 2, lines 1-7,11-33 * * page 4, line 1 - page 5, line 33; figure 2 *	1-12	
A	US 3 875 456 A (KANO TSUYOSHI ET AL) 1 April 1975 (1975-04-01) * abstract * * column 1, lines 1-8 * * column 2, line 41 - column 3, line 64; figures 1-3 *	1	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC)
Place of search The Hague		Date of completion of the search 12 July 2019	Examiner Tinjod, Frank
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 19 16 6740

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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12-07-2019

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2005107420 A	17-11-2005	-----	-----
JP 2004071357 A	04-03-2004	JP 4197109 B2	17-12-2008
		JP 2004071357 A	04-03-2004
-----	-----	-----	-----
US 2005116635 A1	02-06-2005	CN 1902519 A	24-01-2007
		EP 1690120 A1	16-08-2006
		JP 2007513381 A	24-05-2007
		KR 20060113981 A	03-11-2006
		TW 200529472 A	01-09-2005
		US 2005116635 A1	02-06-2005
		WO 2005062098 A1	07-07-2005
-----	-----	-----	-----
US 2004233664 A1	25-11-2004	NONE	
-----	-----	-----	-----
US 6653765 B1	25-11-2003	NONE	
-----	-----	-----	-----
WO 2006087651 A	24-08-2006	-----	-----
US 3875456 A	01-04-1975	JP S48102585 A	22-12-1973
		US 3875456 A	01-04-1975
-----	-----	-----	-----

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 11642089 B [0001]
- US 6452217 B, Wojnarowski [0007]
- US 6600175 B, Baretz [0008]
- US 20040016938 A, Baretz [0008]
- US 6630691 B, Mueller-Mach [0009]
- US 20020030444 A, Muller-Mach [0010]
- US 6696703 B, Mueller-Mach [0010]
- US 20020030060 A, Okazaki [0010]
- US 20020218880 A, Brukilacchio [0011]
- US 20020003233 A, Mueller-Mach [0013]
- US 6501102 B, Mueller-Mach [0013]
- US 6686691 B, Mueller [0014]
- US 6252254 B [0015]
- US 6580097 B, Soules [0015]
- US 6513949 B, Marshall [0016]
- US 6692136 B, Marshall [0016]
- US 20020067773 A, Marshall [0016]
- US 6603258 B, Mueller-Mach [0017]
- US 6616862 B, Srivastava [0018]
- US 6069440 A [0019]
- US 6614179 B [0019]
- US 6608332 B, Shimazu [0019]
- US 6580224 B, Ishii [0019]
- US 20020167014 A, Schlereth [0020]
- US 6734467 B, Schlereth [0020]
- US 2005015736 W [0036]
- WO 2005107420 A2 [0036]

Non-patent literature cited in the description

- **YAMADA K. ; Y. IMAI ; K. ISHII.** Optical simulation of light source devices composed of blue LEDs and YAG phosphor. *Journal of Light and Visual Environment*, 2003, vol. 27 (2), 70-74 [0021]
- **K. YAMADA ; Y. IMAI ; K. ISHII.** *J. Light & Vis. Env.*, 2003, vol. 27 (2), 70 [0108]
- **NARENDHAN, N. ; Y. GU ; J.P. FREYSSINIER ; H. YU ; L. DENG.** Solid-state lighting: Failure analysis of white LEDs. *Journal of Crystal Growth*, 2004, vol. 268 (3-4), 449-456 [0114]